Arizona Department of Transportation

Truck Escape Ramp Study

Final Report

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HDR Engineering

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1.1 Study Process

In recent years, several requests have originated from Arizona Department of Transportation (ADOT) District offices regarding the installation of truck escape ramps (TERs) along specific routes within their districts. At the time, the ADOT Highway Construction program did not include specific projects for the construction of TERs. In response to these requests, ADOT Management decided to collect grade data, horizontal curve data, general site data, traffic data and accident data at existing, planned and potential TER sites. The data was to be compiled into a report format that presented the conditions at existing TER locations as well as those at planned and potential locations. In addition, a review of existing ADOT policy, as well as that of other mountainous states, was to be undertaken to confirm the current state of the practice.

Through every step of the process, ADOT personnel were involved in the decision-making process and format the report was to take. The Priority Programming Manager of the Transportation Planning Division served as the ADOT project manager, with assistance and input provided by the State Traffic Engineer and State Roadway Engineer.

The following chapters lay out an analysis of existing locations within Arizona and the relevant data that was collected, present a review of current policy within Arizona and throughout the country, and investigate potential locations for future TER sites based on requests from various District Engineers and Geographic Information Systems (GIS) analysis. The information presented in this report is intended to assist ADOT in the implementation of additional TERs in future highway construction programs, with the possibility of using Hazard Elimination and Safety (HES) funding when and where appropriate.

Chapter 2
Evaluation of Conditions at Existing Truck Escape Ramp (TER) Sites

2.1 Existing, Planned and Potential Truck Escape Ramp Locations

The purpose of the data gathering process was to better understand existing conditions, current policies, procedures and design criteria used within Arizona for their truck escape ramps (TERs). This knowledge will be a major part of the Arizona Department of Transportation's (ADOT) efforts to provide effective TER facilities in the future.

Data collection included; 1) identifying where ADOT currently has TERs, 2) finding out if there are locations where it may be beneficial to provide a future TER (falling in two categories, a) may be beneficial and b) are currently in the planning process), 3) collecting as-built plans for those areas where there are existing TERs to quantify the design layout, 4) reviewing the photo log of the existing TERs to verify that they have been maintained as originally built, and 5) collecting crash data for those areas where there are existing TERs to evaluate if there is an accident history.

The data presented below was obtained from five primary resources, as indicated below:

- ADOT District Engineers and/or their designee's,
- As-Built Plans,
- ADOT Photo Log,
- ADOT Existing TER Data, and
- Crash Data.

In total, nine District Engineers representing all the ADOT Construction Districts and Reed Henry, manager of the Traffic HES Section, were contacted. Each representative was asked to provide information about existing TERs, where TERs may be needed in the future, and locations where there were TERs being planned. **Table 2.1.1** illustrates our findings.

2.2 As-Built Plans

The available as-built plans were collected for the existing TERs. Plans were also collected for the length of the downgrade associated with the TER. **Table 2.1.1** summarizes the existing, planned and potential TERs within the State. Detailed information pertaining to each individual TER is supplied in **Table 2.2.1** through **Table 2.2.8** and **Figure 2.2.1** through **Figure 2.2.25**.

Table 2.1.1
Existing, Planned and Potential TERs

District	Existing TERs	Potentially Needed TERs	Planned TERs
Flagstaff	I-17 SB, MP 300.37 US 89 SB, MP 524.26	None	
Globe	US 60 WB, MP 228.1[1] SR 77 SB, MP 154.2 SR 77 SB, MP 155.7	US 60 MP 280 (Salt River Canyon)	US 60 WB, MP 280±
Holbrook	None	None	None
Kingman	SR 68 WB, MP 1.29	None	SR 68 WB, moved to MP 5.75
Phoenix	None	SR 87 Sunflower to 4-Peaks	None
Prescott	I-17 NB, MP 283.07	SR 87 NB into Slate Creek SR 260 WB into Verde Valley	None
Safford	SR 80 EB, into Bisbee[2]	US 191 SB at Horseshoe Curve US 191 NB to Three Way US 191 NB at Smelter Hill SR 78 SB MP 153 SR 80 leaving Bisbee	None
Tucson	None	SR 83 NB, MP 42	None
Yuma	None	I-8 EB, MP 20 (Telegraph Pass)	None
TOTAL	8	11	2

[1] Indicates TERs not found at ADOT Engineering Records, but on record with Traffic HES Section.
[2] Indicates TERs not found at ADOT Engineering Records. May have been built by a mining company.

Table 2.2.1
Interstate Route 17 SB TER

Interstate Route 17 SB TER, I-17 MP 300.37	
Variable	**Description**
Mainline Station, Begin TER	5268+50.00
Type of TER	Descending Grade Arrester Bed
Exits	Right side of roadway, on tangent
Length	2844 feet total length 740 feet exit ramp terminal 1884 feet of arrester bed 220 feet of secondary retarder and slopes
Width	Arrester bed varies from 40 feet at point of entry to 26 over roughly 400 feet.
Anchors	Each side of ramp @ 300 foot intervals
Service Road	12 foot wide, paved, between TER and roadway
Grade of TER	-2.000%
Aggregate (if any)	Unspecified
Depth of Aggregate	Tapers from 6" at entry to 24" in 400', maintains 24" for 900', tapers from 24" to 36" in 200', maintains 36" for final 380 feet.
Aggregate Liner	4" CTB
"Last Chance" device	35'W x 29'D x 8'H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown)	Sta. 5550+00.00 – Sta. 5443+51.93 on Tangent (28,200' prior) Sta. 5437+23.46, R = 11,459.16'Lt, L = 629.10' (16,900' prior) Sta. 5402+88.97, R+o = 2,867.12'Rt, L = 1,429.30' (13,400' prior) Sta. 5387+46.82, R+o = 2867.12'Lt, L = 1181.67' (11,900' prior) Sta. 5371+82.44, R+o = 5729.89'Lt, L = 862.92' (10,300' prior) Sta. 5353+10.50, R+o = 2867.12'Rt, L = 1086.97' (8,500' prior) Sta. 5330+99.67, R+o = 2867.12'Lt, L = 1102.22' (6,200' prior) Sta. 5320+46.87, R+o = 4584.23'Rt, L = 843.33' (5,200' prior) Sta. 5311+25.20, R+o = 2296.37'Lt, L = 1000' (4,300' prior) Sta. 5296+60.60, R+o = 3820.70'Lt, L = 826.11' (2,800' prior) Sta. 5283+46.66, R+o = 2296.37'Rt, L = 1628.00' (1,500' prior) **Sta. 5268+50.00 – Truck Escape Ramp** Sta. 5262+55.59, R+o = 2867.12'Lt, 1045.42' (600' after) Sta. 5225+76.43, R+o = 2549.79'Lt, 2706.54' (4,300' after)
Entering Vertical Geometry	Sta. 5545+50, -3.400% (27,700' prior) Sta. 5521+00, -4.222% (25,300' prior) Sta. 5502+00, -1.7815% (23,400' prior) Sta. 5469+50, -6.00% (20,100' prior) Sta. 5449+50, -4.2387% (18,100' prior) Sta. 5441+00, -5.6363% (17,300' prior) Sta. 5430+00, -2.6925% (16,200' prior) Sta. 5396+50, -4.00% (12,700' prior) Sta. 5375+00, -5.6700% (10,700' prior) Sta. 5366+00, -3.3043% (9,800' prior) Sta. 5324+00, -4.0997% (5,500' prior) Sta. 5292+00, -6.00% (2,400' prior) **Sta. 5268+50 – Truck Escape Ramp** Sta. 5225+00, -5.011% (4,400' after) Sta. 5215+00, -4.2126% (5,400' after) Sta. 5192+00, -1.5882% (7,700'

Length of Mountain Grade Above	Greater than 27,700' (5.25 mi)
Length of Mountain Grade Below	Greater than 7,650' (1.45 mi)
Average Percent Grade of Mountain Above	-4.64% over 27,700'
Annual Average Daily Traffic (AADT)	25,294 (Year 2000)
Percent Trucks	17.8% (Year 2000)
Average Number of Accidents per Year	15.8 Total, 1.2 Tractor-Trailer
TER Usage Data Collected Between	10/22/1988 through 06/02/2000
Total Number of Uses	44
Total Number of Warranted Uses[1]	34
Conditions at Bottom of Grade	System Interchange (SR 179 (Sedona))

[1]Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.1
Interstate Route 17 SB TER – Typical Section

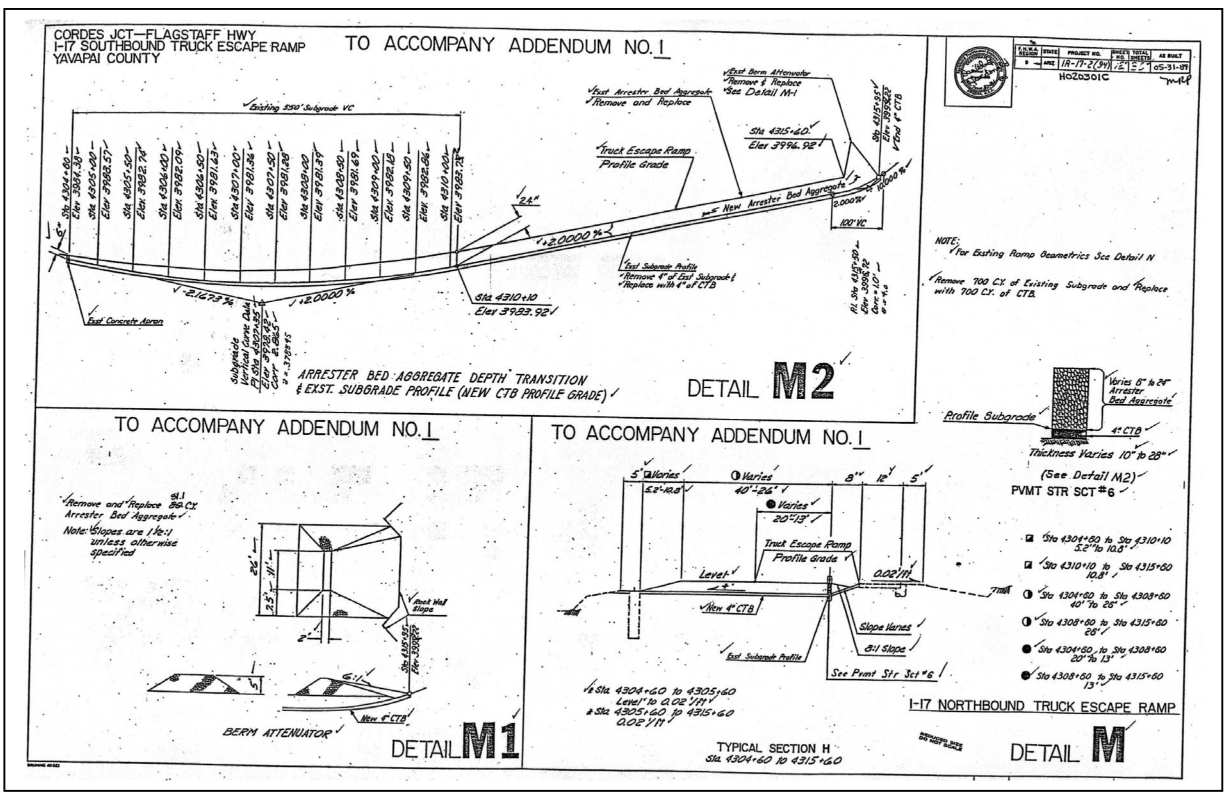


Figure 2.2.2
Interstate Route 17 SB TER – Plan (1 of 1)

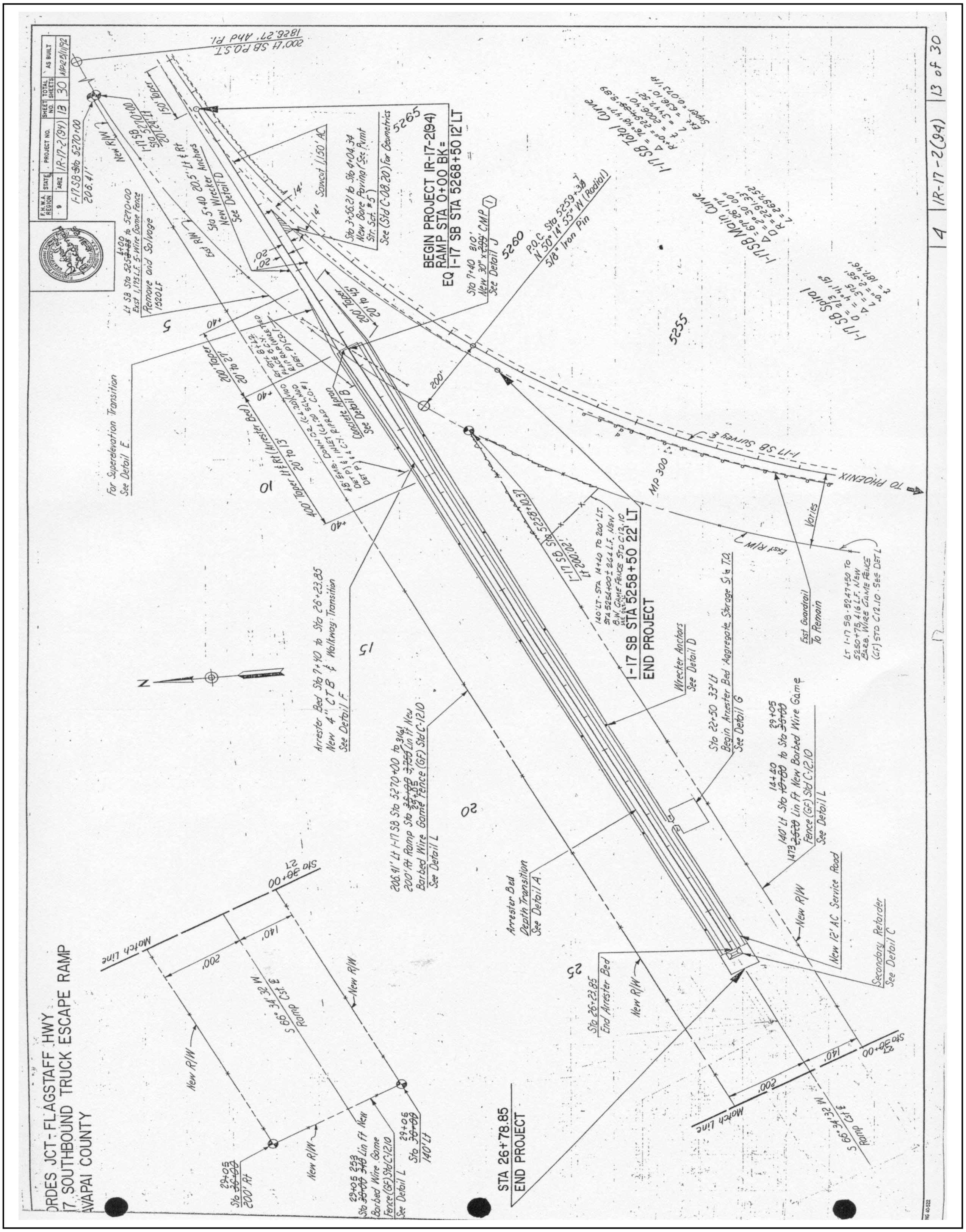


Figure 2.2.3
Interstate Route 17 SB TER – Profile (1 of 1)

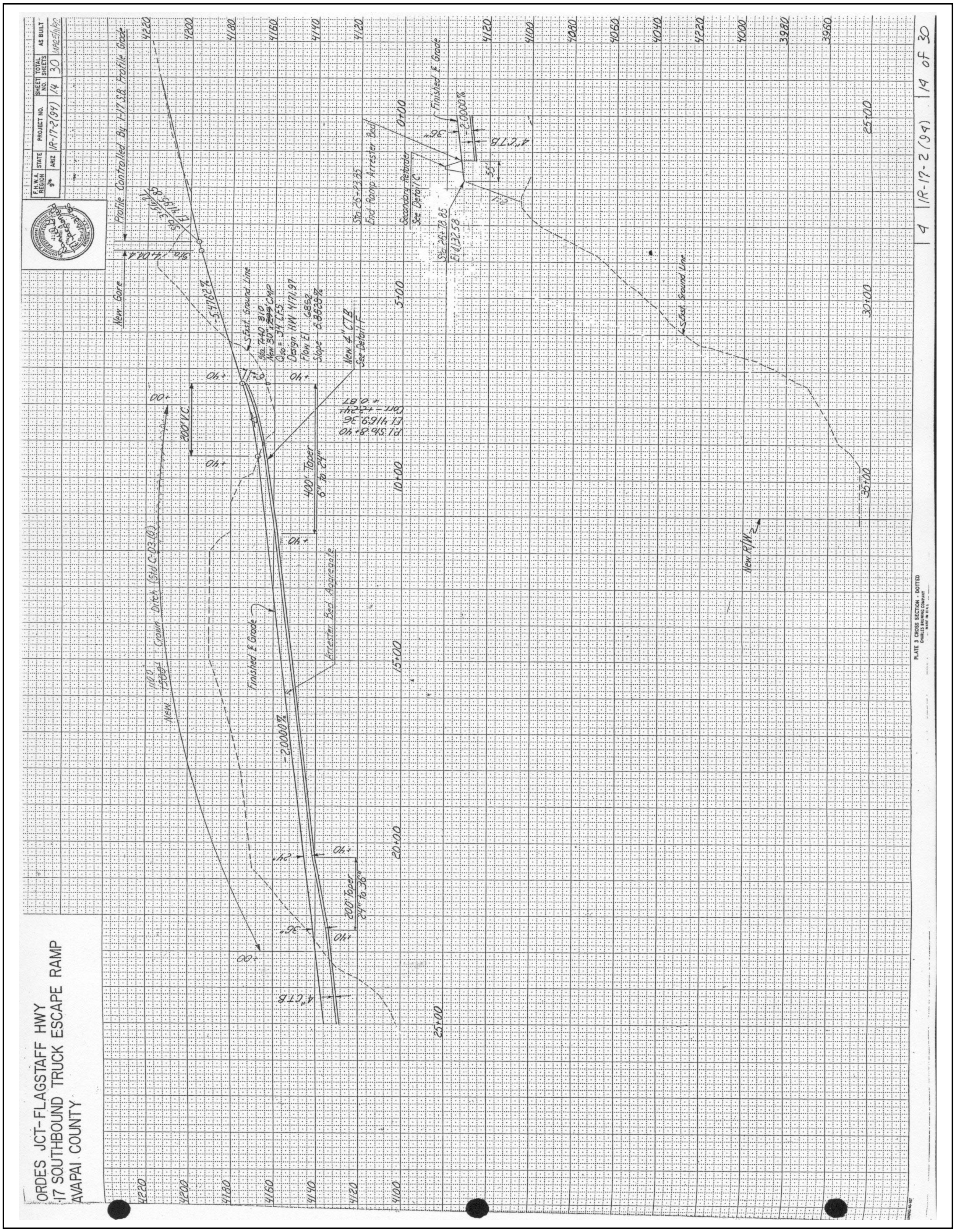


Table 2.2.2
Interstate Route 17 NB TER

Interstate Route 17 NB TER, I-17 MP 283.07	
Variable	**Description**
Mainline Station, begin TER	4290+00.00
Type of TER	Ascending Grade Arrester bed
Exits	Left side of roadway
Length	2560 feet total length 1460 feet exit ramp terminal 1100 feet of arrester bed including secondary retarder
Width	Arrester bed varies from 40 feet at point of entry to 26 over roughly 400 feet.
Anchors	Each side of ramp @ 300 foot intervals
Service Road	12 foot wide, paved, between TER and roadway
Grade of TER	+2.000%
Aggregate (if any)	Pea gravel
Depth of Aggregate	Tapers from 6” at entry to 24” in 550’, maintains 24” for final 550 feet.
Aggregate Liner	Subgrade
“Last Chance” device	26’W x 39.5’D x 5’H aggregate mound (varying slopes)
Entering Horizontal Curve Data (Tangent sections not shown.)	Sta. 4130+81.49, R+o = 2812.17’Rt, L = 3780.28’ (15,900’ prior) Sta. 4162+73.25, R+o = 2292.97’Lt, L = 1293.24’ (12,700’ prior) Sta. 4182+13.00, R+o = 1640.14’Rt, L = 1845.24’ (10,800’ prior) Sta. 4211+72.76, R+o = 1640.14’Lt, L = 2107.62’ (7,800’ prior) Sta. 4225+83.57, R = 4583.66’Rt, L = 547.78’ (6,400’ prior) Sta. 4235+96.39, R+o = 1640.14’Lt, L = 1103.61’ (5,400’ prior) Sta. 4252+97.27, R+o = 1640.14’Rt, L = 1328.57’ (3,700’ prior) Sta. 4278+36.73, R = 4583.66’Lt, L = 1632.00’ (1,200’ prior) **Sta. 4290+00.00 – Truck Escape Ramp** Sta. 4297+40.06, R+o = 1640.14’Rt, L = 1739.52’ (700’ after) Sta. 4313+04.90, R = 1640.14’Lt, L = 1303.16’ (2,300’ after) Sta. 4354+32.29, R = 2865.37’Lt, L = 4014.76’ (6,400’ after)
Entering Vertical Geometry	Sta. 4165+00, -2.8043% (12,500’ prior) Sta. 4184+00, -5.9062% (10,600’ prior) Sta. 4200+00, -6.0000% (9,000’ prior) Sta. 4227+00, -5.8000% (6,300’ prior) Sta. 4247+00, -6.4200% (4,300’ prior) Sta. 4252+00, -5.6000% (3,800’ prior) Sta. 4260+00, -5.8000% (3,000’ prior) **Sta. 4290+00 – Truck Escape Ramp** Sta. 4300+00, -4.6000% (1,000’ after) Sta. 4360+00, -5.2024% (7,000’ after) Sta. 4394+00, -0.9366% (10,400’ after)
Length of Mountain Grade Above	12,500’ (2.37 mi)
Length of Mountain Grade Below	10,400’ (1.97 mi)
Average Percent Grade of Mountain Above	-5.44% over 12,500’
Annual Average Daily Traffic (AADT)	20,180 (Year 2000)
Percent Trucks	21.7% (Year 2000)

Average Number of Accidents per Year	11.8 Total, 0.8 Tractor-Trailer
TER Usage Data Collected Between	03/16/1986 through 02/25/2001
Total Number of Uses	51
Total Number of Warranted Uses[1]	19
Conditions at Bottom of Grade	System Interchange

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.4
Interstate Route 17 NB TER – Typical Section

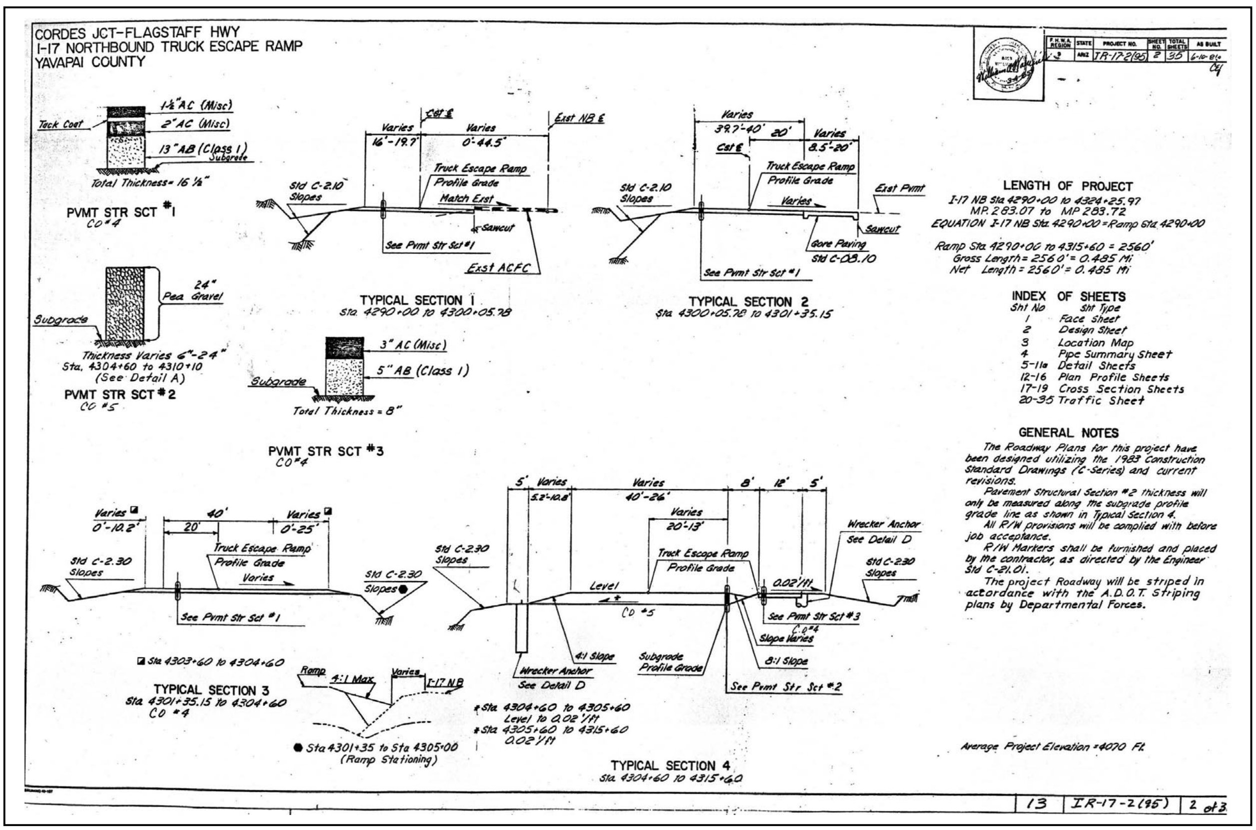


Figure 2.2.5
Interstate Route 17 NB TER – Plan (1 of 2)

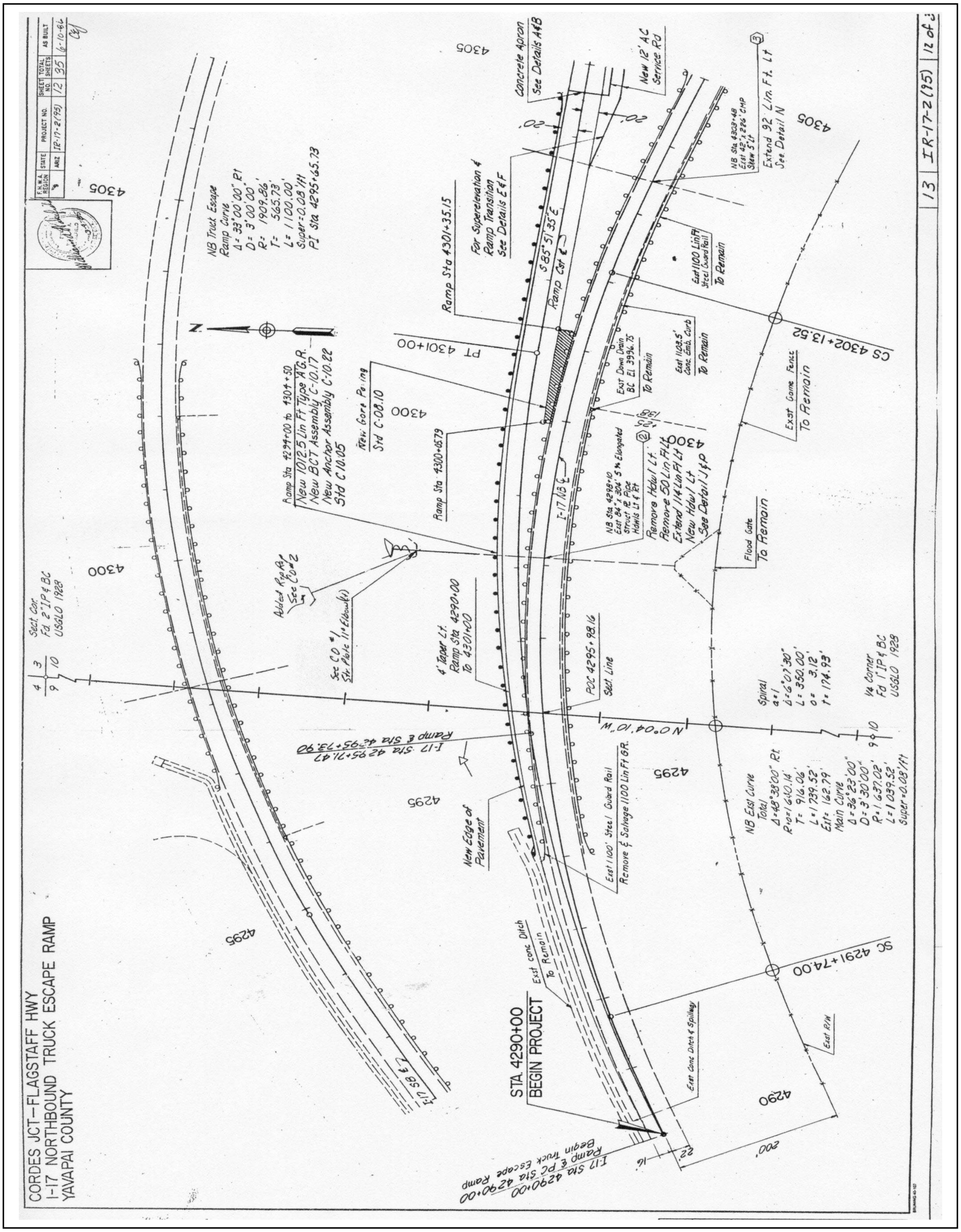


Figure 2.2.6
Interstate Route 17 NB TER – Plan (2 of 2)

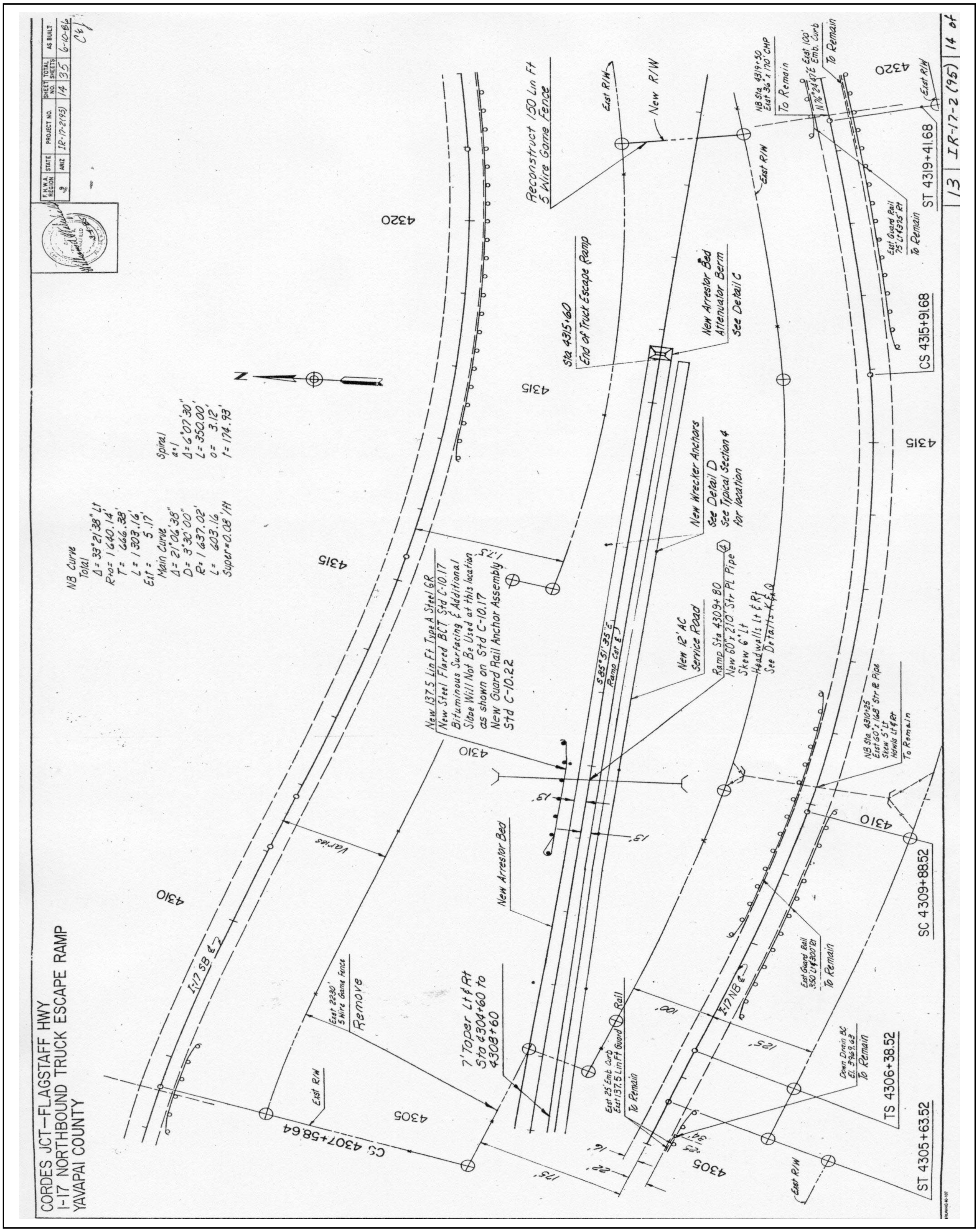


Figure 2.2.7
Interstate Route 17 NB TER – Profile (1 of 2)

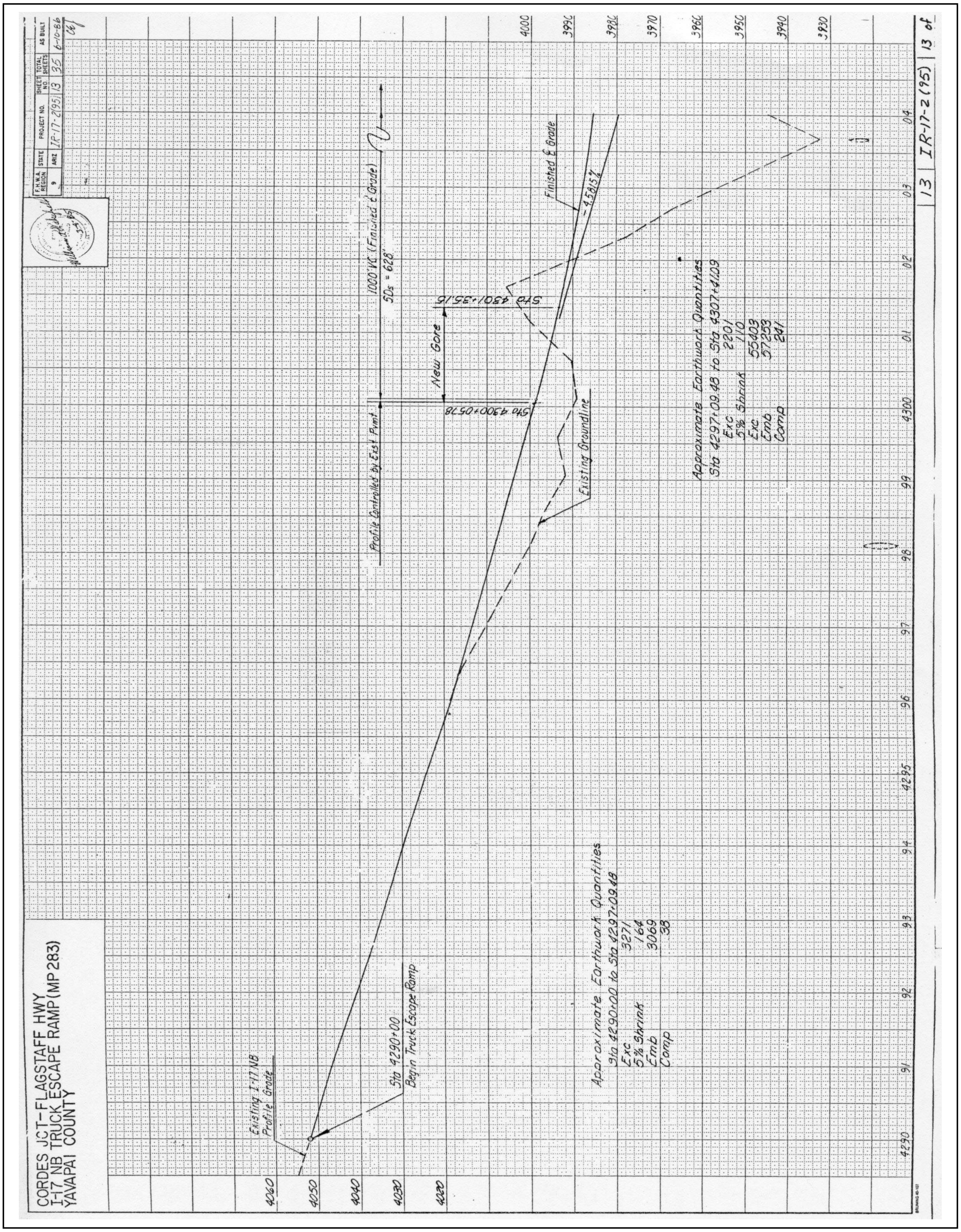


Figure 2.2.8
Interstate Route 17 NB TER – Profile (2 of 2)

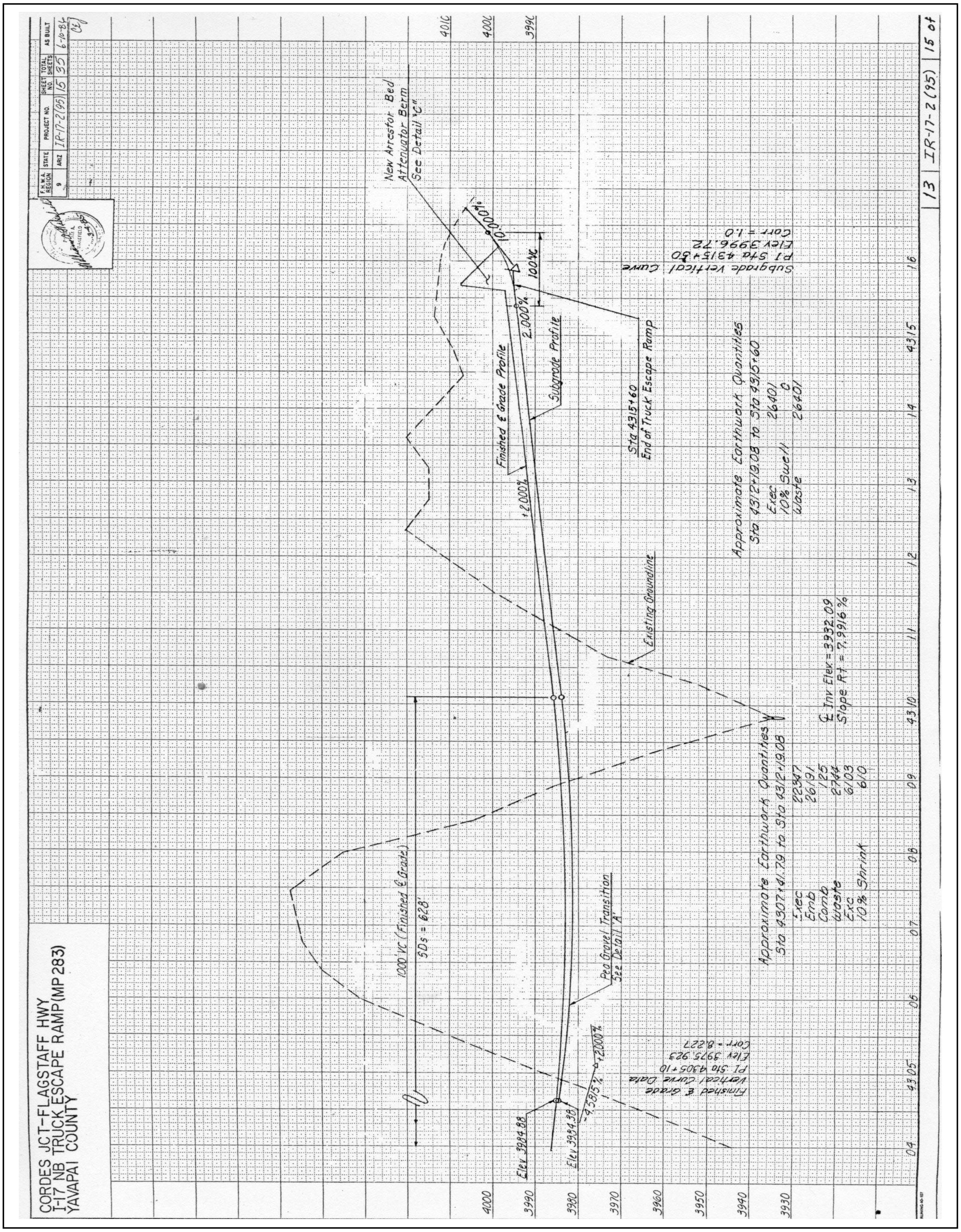


Table 2.2.3
US Route 89 WB TER

U.S. Route 89 WB TER, SR 89 MP 524.26	
Variable	**Description**
Mainline Station begin TER	178+21.38
Type of TER	Descending Grade Arrester Bed
Exits	Right side of roadway
Length	1965 feet total length 660 feet exit ramp terminal 1230 feet of arrester bed 75 feet of secondary retarder and slopes
Width	Arrester bed varies from 40 feet at point of entry to 26 over roughly 400 feet.
Anchors	Each side of ramp @ 300 foot intervals
Service Road	12 foot wide, paved, outside TER away from roadway
Grade of TER	Varies from –3.64% to –3.44% to –1.61% to –3.35%.
Aggregate (if any)	Pea gravel
Depth of Aggregate	Tapers from 12” at entry to 24” in 400’, maintains 24” for final 830 feet.
Aggregate Liner	Compacted subgrade
“Last Chance” device	26’W x 17’D x 5’H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown)	Sta. 377+19.40, R+o = 998.66’Rt, L = 1783.00’ (19,900’ prior) Sta. 360+33.6, R+o = 957.44’Lt, L = 1218.5’ (18,200’ prior) Sta. 342+43.80, R+o = 957.44’Lt, L = 768.8’ (16,400’ prior) Sta. 333+77.5, R+o = 955.56’Lt, L = 782.7’ (15,600’ prior) Sta. 327+37.3, R+o = 1146.28’Rt, L = 400.0’ (14,900’ prior) Sta. 322+22.5, R+o = 2864.79’Lt, L = 385.0’ (14,400’ prior) Sta. 314+69.4, R+o = 956.34’Lt, L = 523.1’ (13,600’ prior) Sta. 307+24.5, R+o = 956.34’Rt, L = 906.4’ (12,900’ prior) Sta. 297+11.1, R+o = 1147.37’Lt, L = 911.0’ (11,900’ prior) Sta. 290+01.9, R+o = 1147.37’Rt, L = 420.00’ (11,200’ prior) Sta. 280+37.8, R+o = 1433.14’Rt, L = 878.34’ (10,200’ prior) Sta. 269+15.8, R+o = 955.56’Lt, L = 868.1’ (9,100’ prior) Sta. 261+15.3, R+o = 955.56’Rt, L = 626.7’ (8,300’ prior) Sta. 252+87.5, R+o = 955.56’Lt, L = 1060.7’ (7,500’ prior) Sta. 237+41.0, R+o = 957.44’Rt, L = 1610.4’ (5,900’ prior) Sta. 218+70.3, R+o = 1433.74’Rt, L = 948.3’ (4,000’ prior) Sta. 209+39.8, R+o = 1433.14’Rt, L = 854.6’ (3,100’ prior) **Sta. 178+21.38 – Truck Escape Ramp** Sta. 205+05.4 – Sta. 158+55.7 on Tangent
Entering Vertical Geometry	Sta. 381+00, -6.00% (20,300’ prior) Sta. 365+50, -2.00% (18,700’ prior) Sta. 353+00, -6.00% (17,500’ prior) Sta. 329+00, -4.00% (15,100’ prior) Sta. 318+00, -4.80% (14,000’ prior) Sta. 305+00, -6.00% (12,700’ prior) Sta. 274+00, -3.70% (9,600’ prior) Sta. 255+00, -6.00% (7,700’ prior) Sta. 222+00, -1.40% (4,400’ prior) Sta. 210+00, -5.00% (3,200’ prior) Sta. 185+00, -3.80% (700’ prior) **Sta. 178+21.38 – Truck Escape Ramp** Sta. 170+00, -2.60% (800’ after)

Length of Mountain Grade Above	20,300' (3.84 mi)
Length of Mountain Grade Below	Greater than 800' (0.15 mi)
Average Percent Grade of Mountain Above	-4.85% over 20,300' (3.84 mi)
Annual Average Daily Traffic (AADT)	3,304 (Year 2000)
Percent Trucks	15.1% (Year 2000)
Average Number of Accidents per Year	9.6 Total, 0.8 Tractor-Trailer
TER Usage Data Collected Between	NO DATA ON RECORD.
Total Number of Uses	
Total Number of Warranted Uses[1]	
Conditions at Bottom of Grade	Intersection with US Route 89A

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.9
US Route 89 WB TER – Typical Section

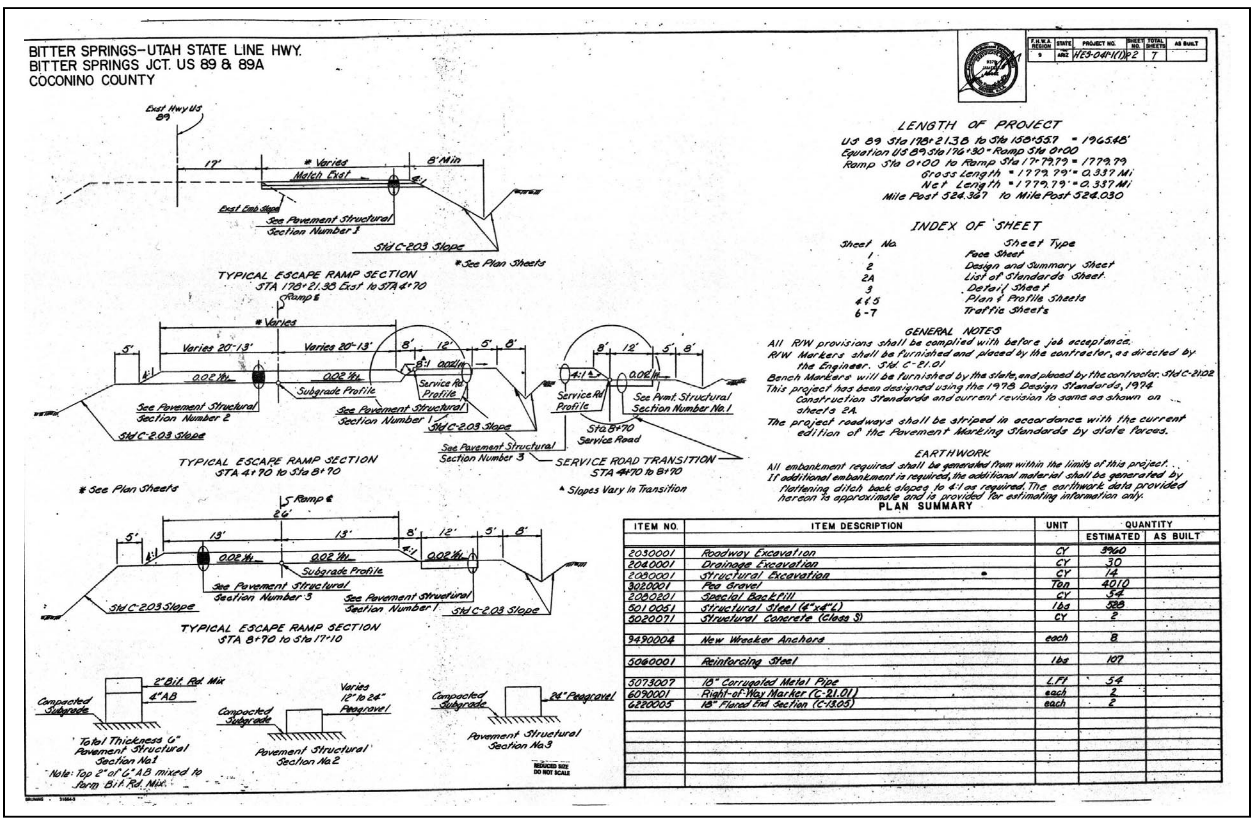


Figure 2.2.10
US Route 89 WB TER – Plan and Profile (1 of 2)

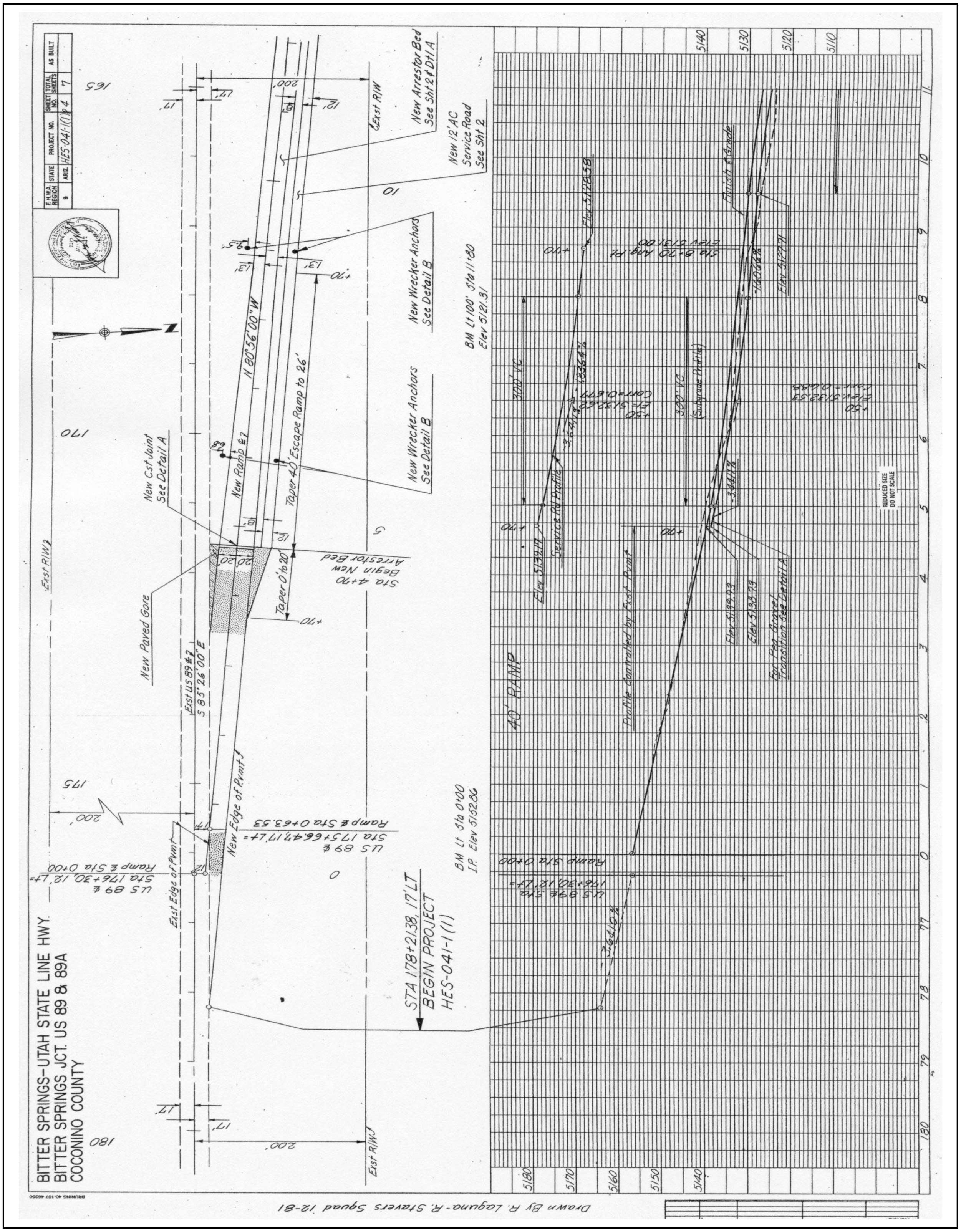


Figure 2.2.11
US Route 89 WB TER – Plan and Profile (2 of 2)

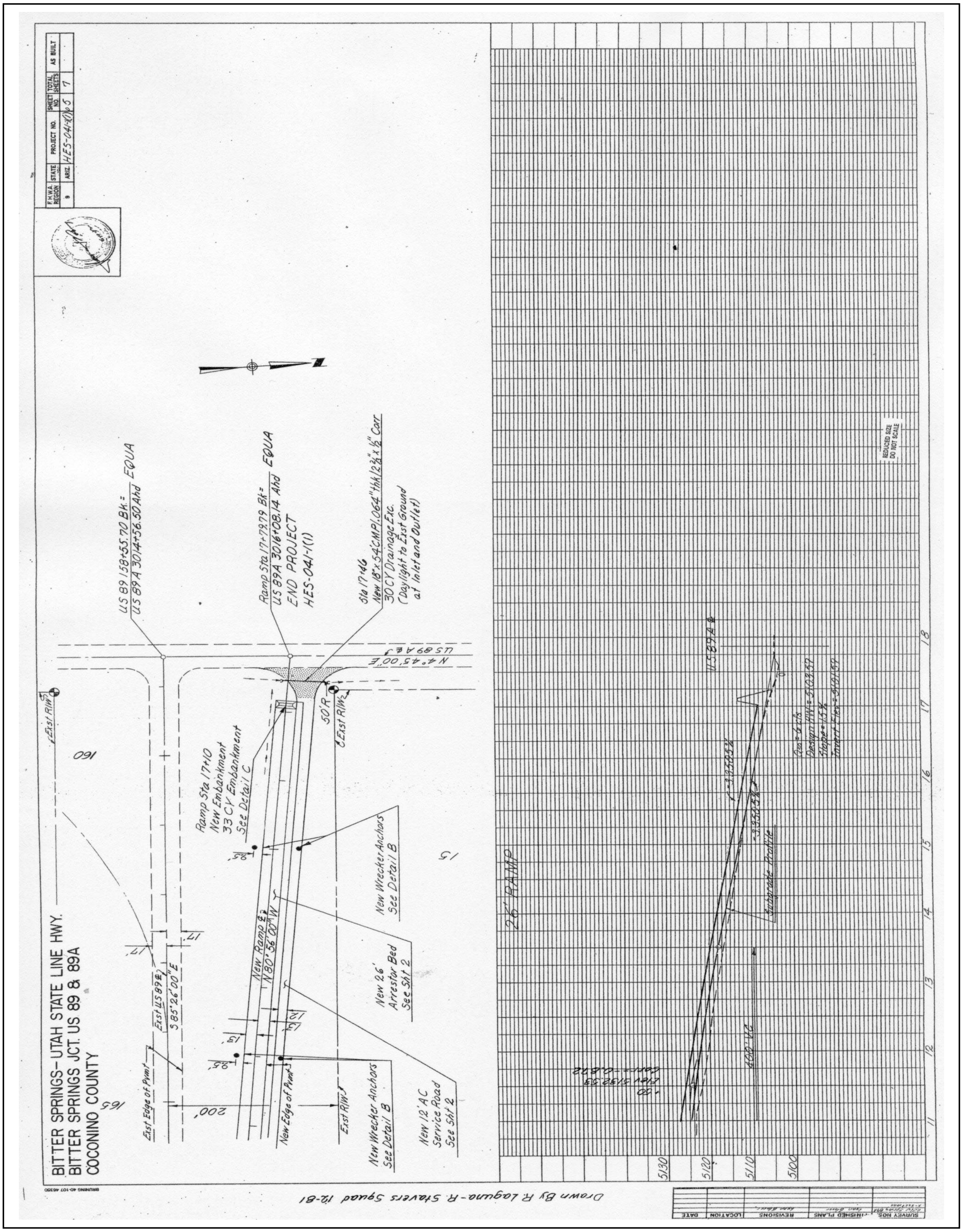


Table 2.2.4
State Route 68 WB TER

State Route 68 WB TER, SR 68 MP 1.29	
Variable	**Description**
Mainline Station begin TER	92+50.00 (From DCR)
Type of TER	Descending Grade Arrester Bed
Exits	Right side of roadway
Length	2500 feet total length 973 feet exit ramp terminal 1327 feet of arrester bed including secondary retarder 200 feet service road return
Width	Arrester bed varies from 40 feet at point of entry to 26 over roughly 400 feet.
Anchors	Each side of ramp @ 200 foot intervals
Service Road	12 foot wide, paved, outside TER away from roadway
Grade of TER	-4.1189%
Aggregate (if any)	Yes, unspecified
Depth of Aggregate	Tapers from 6" at entry to 48" in 150', maintains 48" for final 1177 feet.
Aggregate Liner	Asphalt concrete and engineering fabric
"Last Chance" device	26'W x 17'D x 5'H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown.)	Sta. 656+17.56, R = 3819.72'Rt, L = 768.88' (56400' prior) Sta. 641+21.10, R = 5729.58'Lt, L = 600.48' (54900' prior) Sta. 626+86.91, R = 5729.58'Lt, L = 756.27' (53400' prior) Sta. 610+88.47, R = 2864.79'Rt, L = 596.40' (51800' prior) Sta. 599+48.71, R+o = 1208.22'Lt, L = 1074.40' (50700' prior) Sta. 554+65.15, R = 11459.16'Rt, L = 859.58' (46200' prior) Sta. 533+41.92, R+o = 1433.37'Rt, L = 3303.77' (44100' prior) Sta. 501+03.03, R+o = 1911.82'Lt, L = 738.07' (40900' prior) Sta. 473+19.62, R+o = 1209.76'Lt, L = 1555.96' (38100' prior) Sta. 444+18.32, R = 2864.79'Rt, L = 879.67' (35200' prior) Sta. 423+83.92, R = 2864.79'Lt, L = 1167.13' (33100' prior) Sta. 365+92.73, R = 2546.48'Rt, L = 1583.54' (27300' prior) Sta. 253+11.72, R = 7639.44'Lt, L = 1158.42' (16100' prior) Sta. 236+41.45, R+o = 1910.73'Rt, L = 1277.77' (14400' prior) Sta. 201+26.24, R = 11459.16'Lt, L = 724.11' (10900' prior) Sta. 171+00.54, R = 2864.79'Lt, L = 1028.75' (7900' prior) Sta. 151+37.23, R = 11459.16'Lt, L = 918.54' (5900' prior) Sta. 102+85.77, R = 2864.79'Rt, L = 760.98' (1000' prior) **Sta. 92+50.00 – Truck Escape Ramp** Sta. 73+52.18, R+o = 1910.73'Rt, L = 824.65' (1900' after)
Entering Vertical Geometry	Sta. 650+40, -6.0000% (55800' prior) Station Equation: 576+28.18Bk = 592+92.71Ahd (48400' prior) Sta. 560+00, -4.7039% (46800' prior) Sta. 540+00, -5.9524% (44800' prior) Sta. 519+00, -5.5526% (42700' prior) Sta. 500+00, -4.8306% (40800' prior) Sta. 466+00, -5.0600% (37400' prior) Sta. 445+00, -3.6326% (35300' prior) Sta. 427+50, -5.1693% (33500' prior) Sta. 395+00, -5.9732% (30300' prior) Sta. 355+00, -4.9291% (26300' prior) Sta. 284+50, -2.7778% (19200' prior) Sta. 275+50, -4.4000% (18300' prior)

	Sta. 255+50, -3.0000% (16300' prior) Sta. 244+50, -6.0000% (15200' prior) Sta. 226+50, -4.3947% (13400' prior) Sta. 207+50, -5.0491% (11500' prior) Sta. 180+00, -5.5361% (8800' prior) Sta. 162+00, -5.0762% (6800' prior) Sta. 151+50, -4.5826% (5900' prior) Sta. 140+00, -4.8850% (4800' prior) Sta. 120+00, -3.7075% (2800' prior) Sta. 112+00, -5.0876% (2000' prior) **Sta. 92+50 – Truck Escape Ramp** Sta. 87+00, -3.7713% (600' after)
Length of Mountain Grade Above	55,790 feet (10.57 mi)
Length of Mountain Grade Below	Greater than 600' (0.11 mi)
Average Percent Grade of Mountain Above	-5.11% over 55,790' (10.57 mi)
Annual Average Daily Traffic (AADT)	8,201 (Year 2000)
Percent Trucks	4.5% (Year 2000)
Average Number of Accidents per Year	8.1 Total, 0.5 Tractor-Trailer
TER Usage Data Collected Between	07/27/1986 through 05/01/1996
Total Number of Uses	25
Total Number of Warranted Uses[1]	22
Conditions at Bottom of Grade	Intersection

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.12
State Route 68 WB TER – Typical Section

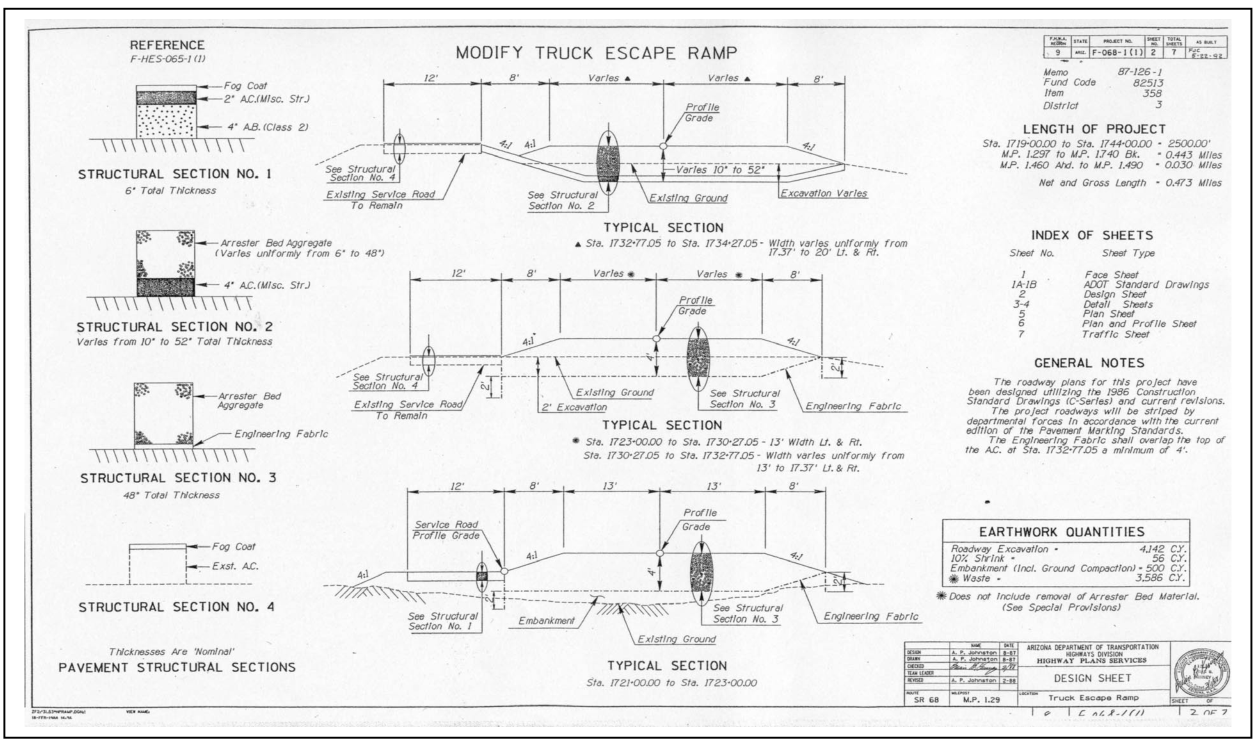


Figure 2.2.13
State Route 68 WB TER – Plan and Profile (1 of 1)

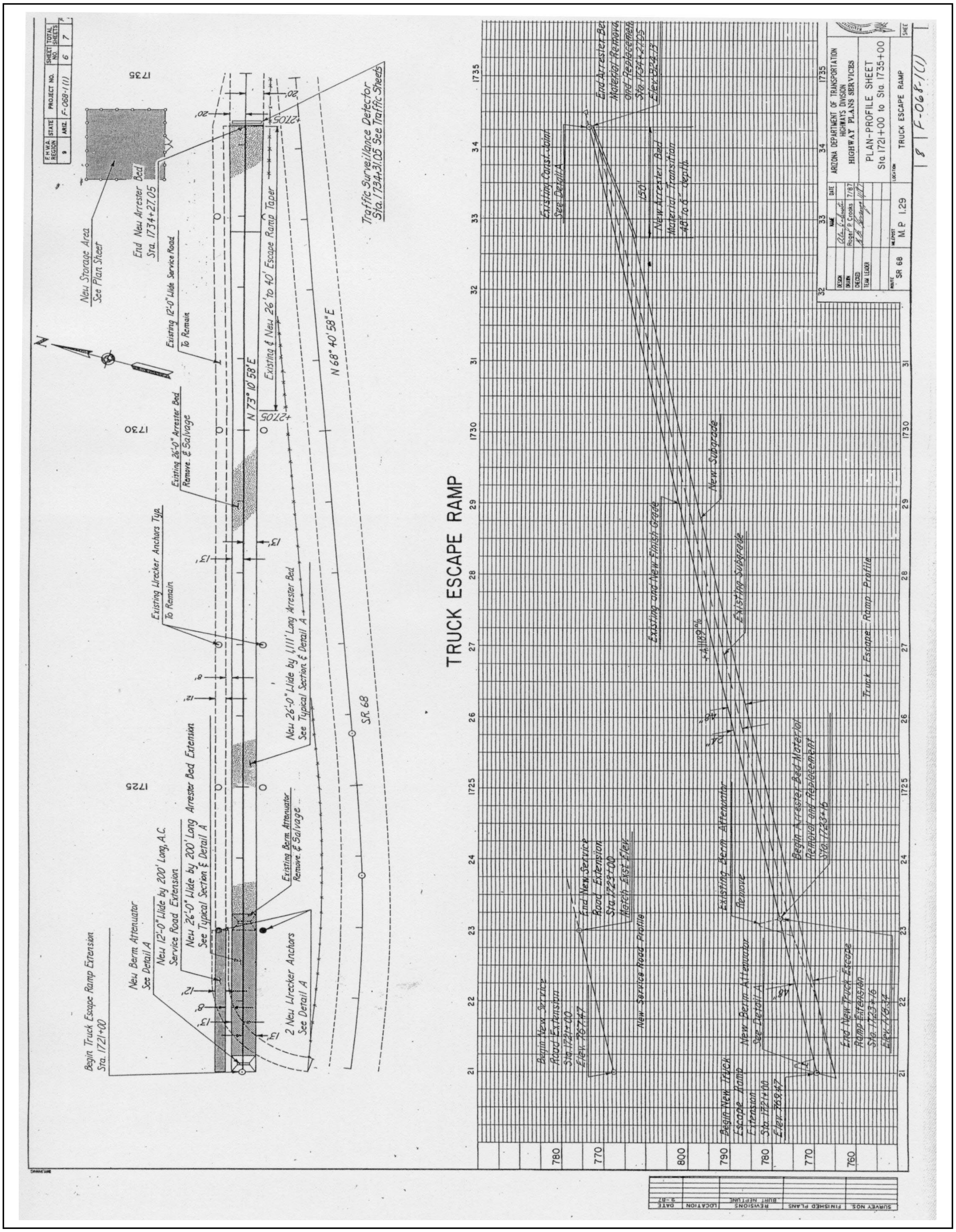


Table 2.2.5
State Route 68 WB TER

State Route 68 TER, SR 68 MP 5.75 (New Design/Build)	
Variable	**Description**
Mainline Station begin TER	303+67.55
Type of TER	Descending Grade Arrester Bed
Exits	Right side of roadway
Length	2495 feet total length 900 feet exit ramp terminal 1285 feet of arrester bed including secondary retarder 310 feet service road return
Width	Arrester bed width of 34 feet throughout.
Anchors	Each side of ramp @ 150 foot intervals
Service Road	13.5 foot wide (including anchors), paved, between TER and roadway
Grade of TER	Varies from -4.4492% to –2.3283%
Aggregate (if any)	Unspecified, reused from original TER
Depth of Aggregate	Tapers from 6" at entry to 36" in 150', maintains 36" for final 1111 feet.
Aggregate Liner	3" asphalt concrete lining
"Last Chance" device	34'W x 17'D x 5'H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown.)	Sta. 656+17.56, R = 3819.72'Rt, L = 768.88' (35300' prior) Sta. 641+21.10, R = 5729.58'Lt, L = 600.48' (33800' prior) Sta. 626+86.91, R = 5729.58'Lt, L = 756.27' (32300' prior) Sta. 610+88.47, R = 2864.79'Rt, L = 596.40' (30700' prior) Sta. 599+48.71, R+o = 1208.22'Lt, L = 1074.40' (29600' prior) Sta. 554+65.15, R = 11459.16'Rt, L = 859.58' (25100' prior) Sta. 533+41.92, R+o = 1433.37'Rt, L = 3303.77' (23000' prior) Sta. 501+03.03, R+o = 1911.82'Lt, L = 738.07' (19700' prior) Sta. 473+19.62, R+o = 1209.76'Lt, L = 1555.96' (17000' prior) Sta. 444+18.32, R = 2864.79'Rt, L = 879.67' (14100' prior) Sta. 423+83.92, R = 2864.79'Lt, L = 1167.13' (12000' prior) Sta. 365+92.73, R = 2546.48'Rt, L = 1583.54' (6200' prior) **Sta. 303+67.55 – Truck Escape Ramp** Sta. 253+11.72, R = 7639.44'Lt, L = 1158.42' (5100' after) Sta. 236+41.45, R+o = 1910.73'Rt, L = 1277.77' (6700' after) Sta. 201+26.24, R = 11459.16'Lt, L = 724.11' (10200' after) Sta. 171+00.54, R = 2864.79'Lt, L = 1028.75' (13300' after) Sta. 151+37.23, R = 11459.16'Lt, L = 918.54' (15200' after) Sta. 102+85.77, R = 2864.79'Rt, L = 760.98' (20100' after) Sta. 73+52.18, R+o = 1910.73'Rt, L = 824.65' (23000' after)
Entering Vertical Geometry	Sta. 650+40, -6.0000% (34700' prior) Station Equation: 576+28.18Bk = 592+92.71Ahd (27300' prior) Sta. 560+00, -4.7039% (25600' prior) Sta. 540+00, -5.9524% (23600' prior) Sta. 519+00, -5.5526% (21500' prior) Sta. 500+00, -4.8306% (19600' prior) Sta. 466+00, -5.0600% (16200' prior) Sta. 445+00, -3.6326% (14100' prior) Sta. 427+50, -5.1693% (12400' prior) Sta. 395+00, -5.9732% (9100' prior) Sta. 355+00, -4.9291% (5100' prior) **Sta. 303+67 – Truck Escape Ramp** Sta. 284+50, -2.7778% (1900' after)

	Sta. 275+50, -4.4000% (2800' after) Sta. 255+50, -3.0000% (4800' after) Sta. 244+50, -6.0000% (5900' after) Sta. 226+50, -4.3947% (7700' after) Sta. 207+50, -5.0491% (9600' after) Sta. 180+00, -5.5361% (12400' after) Sta. 162+00, -5.0762% (14400' after) Sta. 151+50, -4.5826% (15200' after) Sta. 140+00, -4.8850% (16400' after) Sta. 120+00, -3.7075% (18400' after) Sta. 112+00, -5.0876% (19200' after) Sta. 87+00, -3.7713% (21700' after)
Length of Mountain Grade Above	34,700 feet (6.57 mi)
Length of Mountain Grade Below	Greater than 21,700 feet (4.11 mi)
Average Percent Grade of Mountain Above	-5.34% over 34,700' (6.57 mi)
Annual Average Daily Traffic (AADT)	8,201 (Year 2000)
Percent Trucks	4.5% (Year 2000)
Average Number of Accidents per Year	8.1 Total, 0.5 Tractor-Trailer
TER Usage Data Collected Between	NEW LOCATION, NO DATA ON RECORD.
Total Number of Uses	
Total Number of Warranted Uses[1]	
Conditions at Bottom of Grade	Intersection

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.14
State Route 68 WB TER – Typical Section

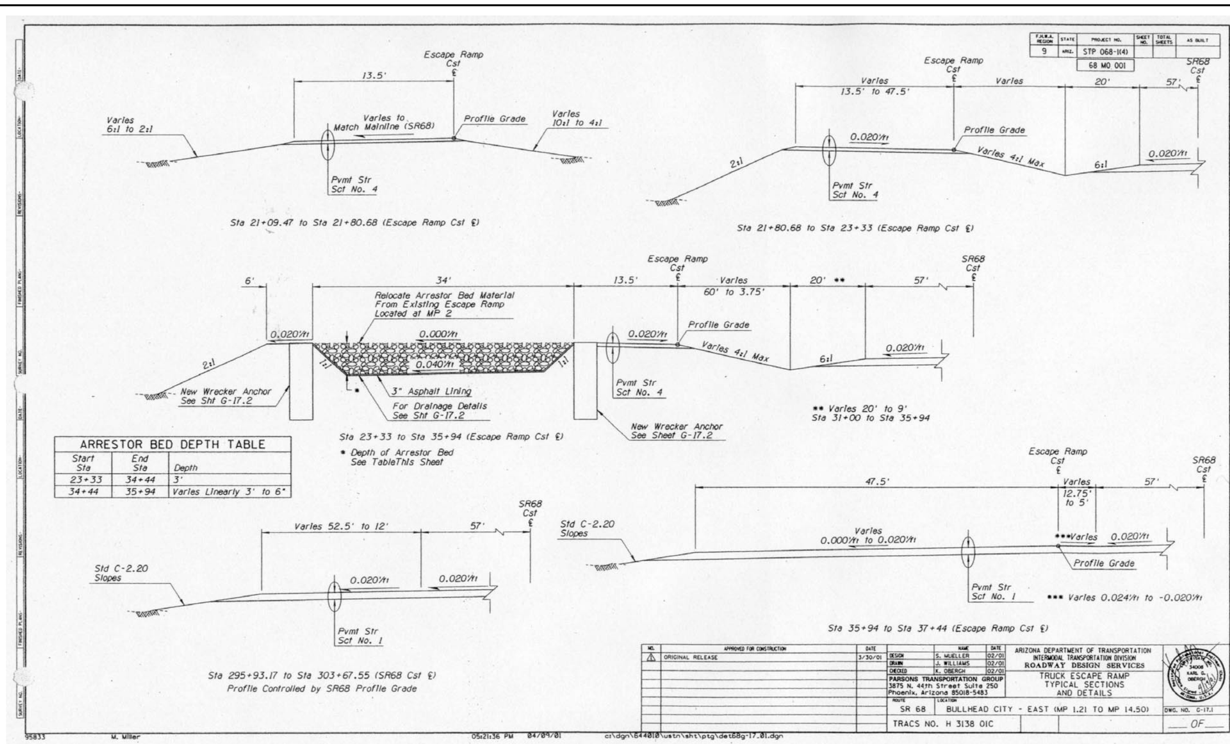


Figure 2.2.15
State Route 68 WB TER – Plan and Profile (1 of 2)

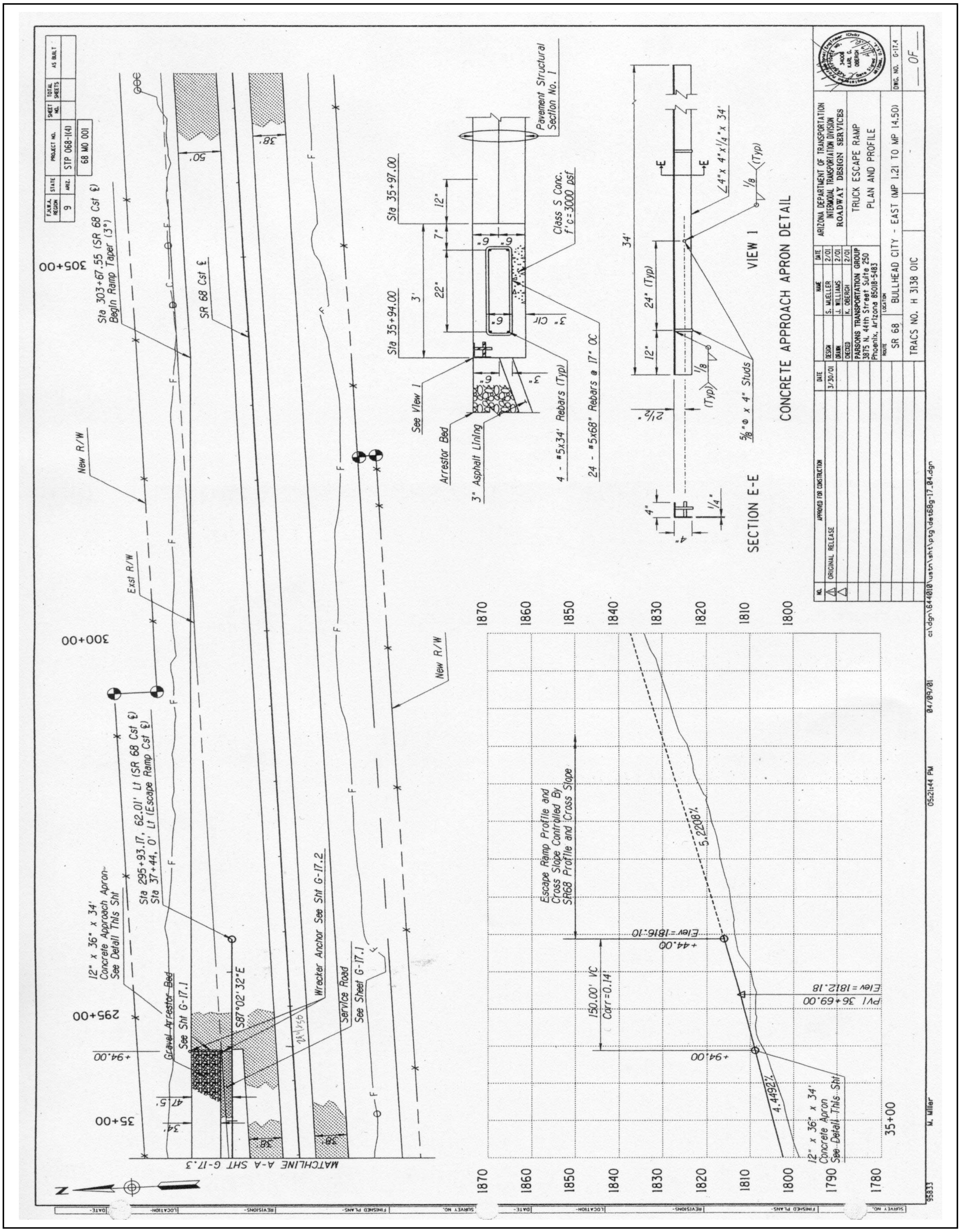


Figure 2.2.16
State Route 68 WB TER – Plan and Profile (2 of 2)

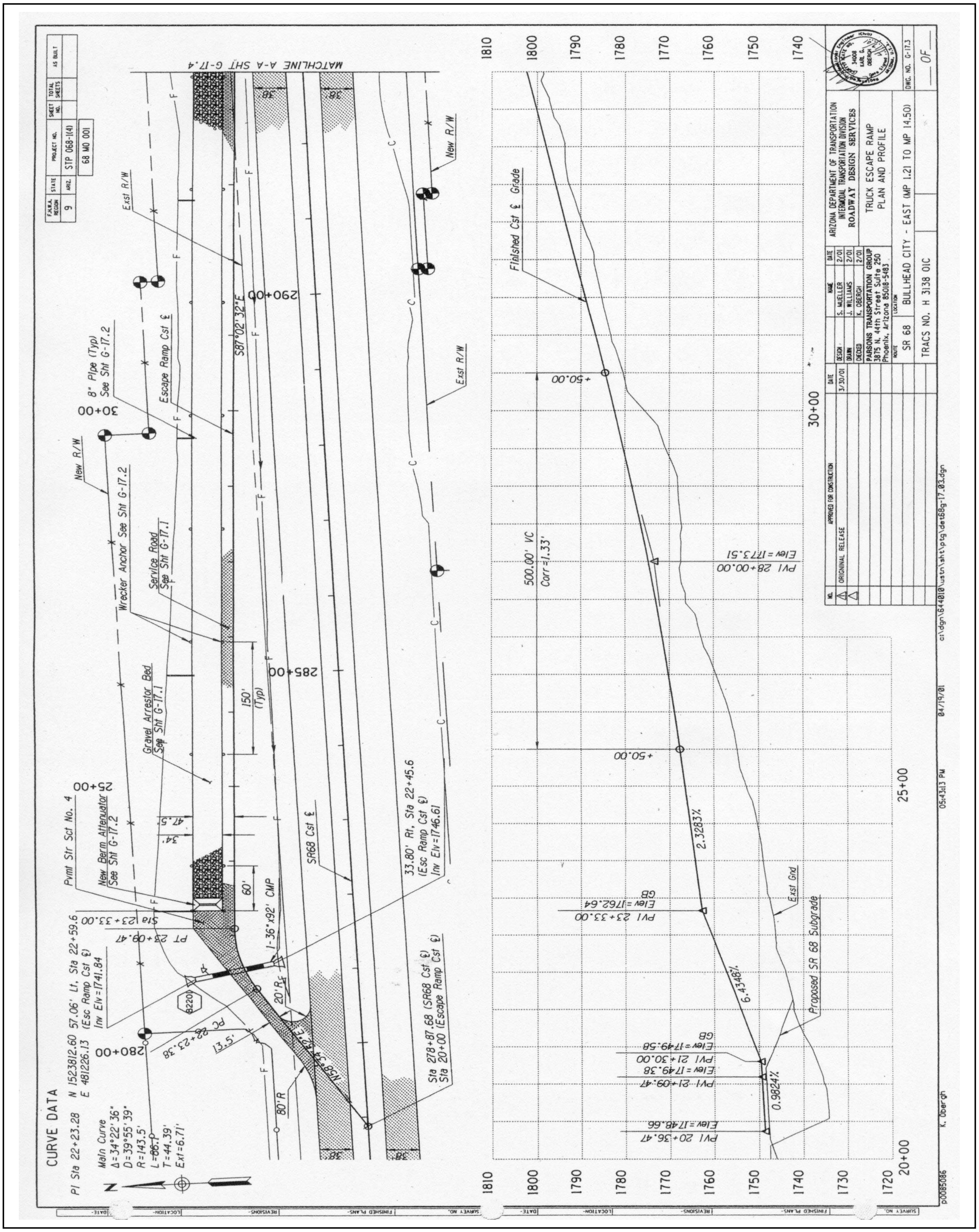


Table 2.2.6
State Route 77 SB TER

State Route 77 SB TER, SR 77 MP 154.2	
Variable	**Description**
Mainline Station begin TER	3197+47.05
Type of TER	Descending Grade Arrester Bed
Exits	Right side of roadway
Length	2704 feet total length 1700 feet exit ramp terminal 1004 feet of arrester bed including secondary retarder
Width	Arrester bed width of 34 feet throughout.
Anchors	Service road side of ramp @ 150 foot intervals
Service Road	13.5 foot wide (including anchors), paved, between TER and roadway
Grade of TER	Varies from –7.9500% to –1.2500%
Aggregate (if any)	Unspecified
Depth of Aggregate	Tapers from 6" at entry to 36" in 150', maintains 36" for final 854 feet.
Aggregate Liner	4" CTB
"Last Chance" device	26'W x 20'D x 5'H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown.)	Sta. 3422+27.48, R = 954.93'Lt, L = 791.53' (22,500' prior) Sta. 3409+55.14, R = 2291.83'Lt, L = 780.00' (21,200' prior) Sta. 3397+79.93, R = 716.20'Rt, L = 943.09' (20,000' prior) Sta. 3388+49.77, R = 716.20'Lt, L = 807.85' (19,100' prior) Sta. 3379+91.88, R = 1432.40'Rt, L = 707.92' (18,200' prior) Sta. 3369+66.09, R = 2289.83'Lt, L = 1243.67' (17,200' prior) Sta. 3356+52.15, R = 1432.40'Lt, L = 700.21' (15,900' prior) Sta. 3348+23.73, R = 954.93'Rt, L = 934.17' (15,100' prior) Sta. 3337+60.11, R = 1432.40'Lt, L = 1093.27' (14,000' prior) Sta. 3329+30.84, R = 954.93'Rt, L = 525.40' (13,200' prior) Sta. 3320+37.13, R = 716.20'Rt, L = 971.18' (12,300' prior) Sta. 3310+61.13, R = 954.93'Lt, L = 940.83' (11,300' prior) Sta. 3284+75.37, R = 954.93'Lt, L = 906.62' (8,700' prior) Sta. 3265+58.40, R = 2291.83'Rt, L = 550.00' (6,800' prior) Sta. 3256+82.58, R = 954.93'Lt, L = 997.78' (5,900' prior) Sta. 3245+72.13, R = 2291.83'Rt, L = 452.78' (4,800' prior) Sta. 3236+77.57, R = 954.93'Lt, L = 755.00' (3,900' prior) Sta. 3227+32.76, R = 954.93'Rt, L = 1034.63' (3,000' prior) Sta. 3206+28.54, R = 1909.86'Lt, L = 600.86' (900' prior) **Sta. 3197+47.05 – Truck Escape Ramp** Sta. 3195+58.54, R = 1432.40'Rt, L = 1336.81' (200' after) Sta. 3178+34.92, R = 1637.02'Lt, L = 2013.01' (1,900' after) Sta. 3143+06.54, R = 2864.79'Lt, L = 1401.94' (5,400' after) Sta. 3038+04.88, R = 5729.58'Rt, L = 2275.28' (15,900' after)
Entering Vertical Geometry	Sta. 3423+00, -5.0000% (22,600' prior) Sta. 3410+50, -0.3510% (21,300' prior) Sta. 3400+50, -7.9850% (20,300' prior) Sta. 3381+50, -3.4290% (18,400' prior) Sta. 3373+50, -7.1000% (17,600' prior) Sta. 3340+00, -4.0000% (14,300' prior) Sta. 3333+50, +1.1667% (13,600' prior) Sta. 3321+50, -8.0000% (12,400' prior) Sta. 3309+50, +1.5440% (11,200' prior) Sta. 3300+50, -6.6000% (10,300' prior)

	Sta. 3264+00, -8.0000% (6,700‘ prior) Sta. 3233+00, -5.8571% (3,600‘ prior) Sta. 3226+00, -6.0000% (2,900‘ prior) Sta. 3208+00, -8.0000% (1,100‘ prior) **Sta. 3197+47.05 – Truck Escape Ramp** Sta. 3175+00, -6.0000% (2,200‘ after) Sta. 3154+50, -1.5135% (4,300’ after) Sta. 3136+00, +2.5000% (6,100‘ after) Sta. 3130+00, +0.7222% (6,700‘ after) Sta. 3112+00, -3.3889% (8,500‘ after) Sta. 3094+50, +0.8400% (10,300‘ after) Sta. 3082+00, -2.8333% (11,500‘ after) Sta. 3065+00, -3.8462% (13,200‘ after) Sta. 3052+00, -7.0000% (14,500‘ after) Sta. 3043+00, -2.5000% (15,400‘ after) Sta. 3035+00, -3.6153% (16,200‘ after) Sta. 3022+00, -3.0714%, (17,500‘ after)
Length of Mountain Grade Above	Greater than 22,600’ (4.28 mi)
Length of Mountain Grade Below	Greater than 17,500’ (3.31 mi)
Average Percent Grade of Mountain Above	-5.9638% over 22,600’ (4.28 mi)
Annual Average Daily Traffic (AADT)	1,609 (Year 2000)
Percent Trucks	10.1% (Year 2000)
Average Number of Accidents per Year	8.6 Total, 0.9 Tractor-Trailer
TER Usage Data Collected Between	03/09/1991 through 12/20/2000
Total Number of Uses	10
Total Number of Warranted Uses[1]	7
Conditions at Bottom of Grade	Unknown

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.17
State Route 77 SB TER – Typical Section

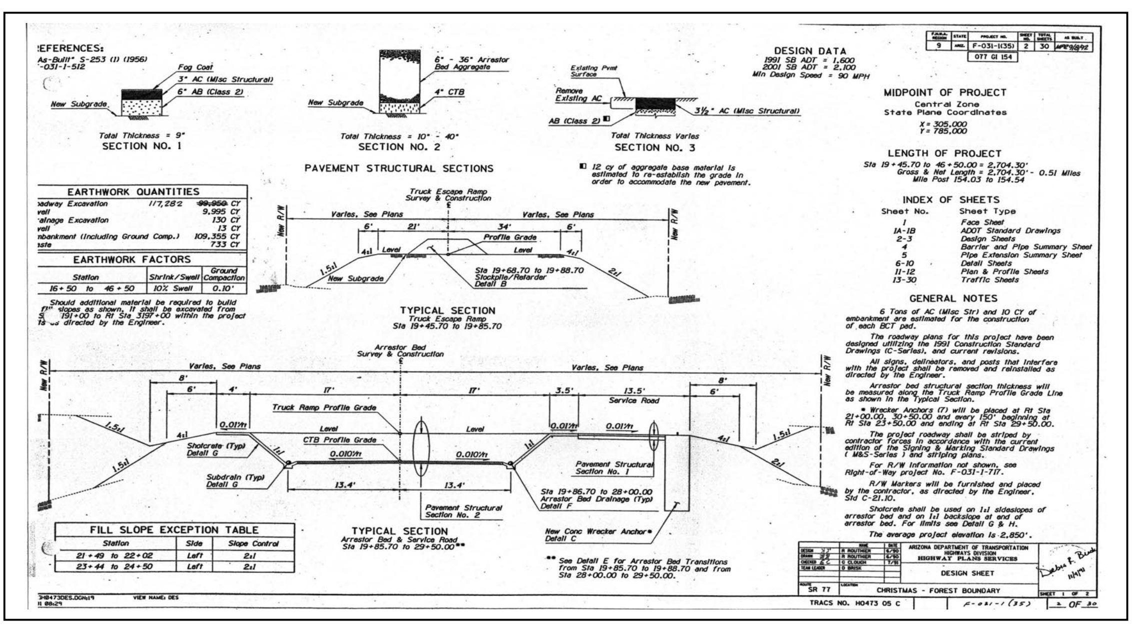


Figure 2.2.18
State Route 77 SB TER – Plan and Profile (1 of 2)

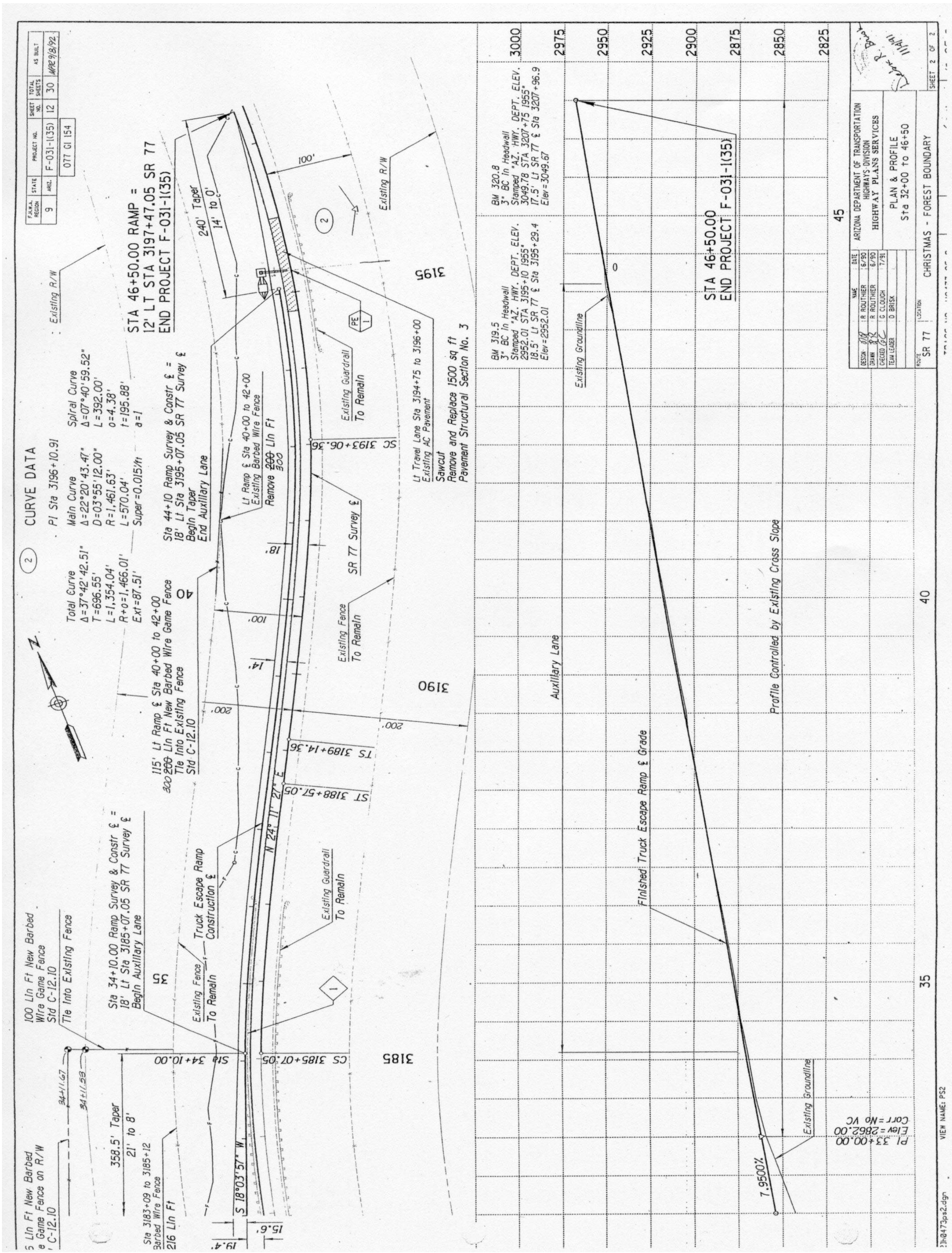


Figure 2.2.19
State Route 77 SB TER – Plan and Profile (2 of 2)

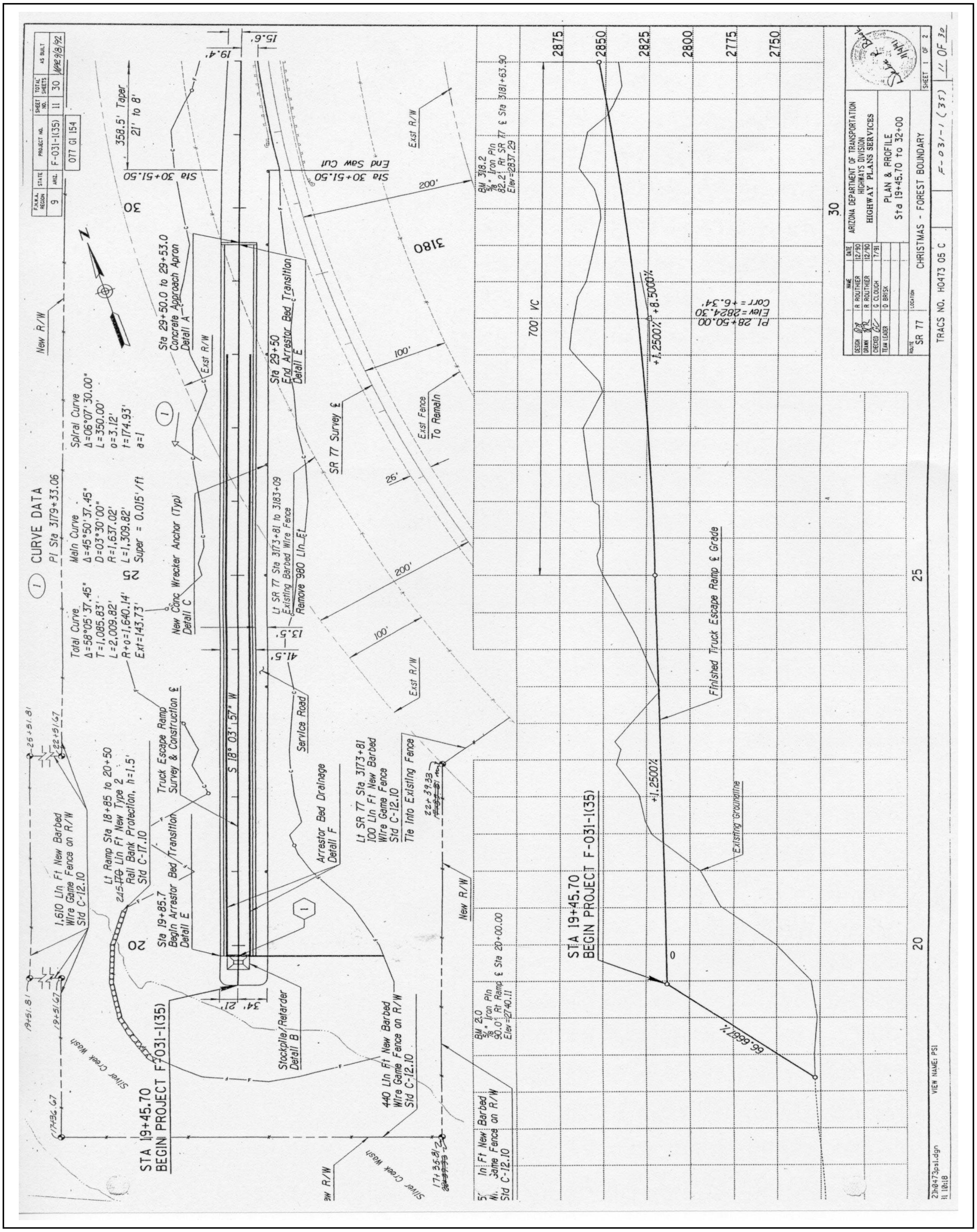


Table 2.2.7
State Route 77 SB TER

State Route 77 SB TER, SR 77 MP 155.7	
Variable	**Description**
Mainline Station begin TER	3274+21.72
Type of TER	Descending/Ascending Grade Arrester Bed
Exits	Right side of roadway
Length	2760 feet total length 1690 feet exit ramp terminal 1070 feet of arrester bed including secondary retarder
Width	Arrester bed width of 48 feet throughout.
Anchors	Each side of ramp @ 150 foot intervals
Service Road	13.5 foot wide (not including anchors), paved, between TER and roadway
Grade of TER	Varies from –7.77% to +2.000%
Aggregate (if any)	Unspecified
Depth of Aggregate	Tapers from 6” at entry to 48” in 150’, maintains 48” for final 850 feet.
Aggregate Liner	4” CTB
“Last Chance” device	35’W x 29’D x 8’H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown.)	Sta. 3422+27.48, R = 954.93’Lt, L = 791.53’ (14,800’ prior) Sta. 3409+55.14, R = 2291.83’Lt, L = 780.00’ (13,500‘ prior) Sta. 3397+79.93, R = 716.20’Rt, L = 943.09’ (12,400‘ prior) Sta. 3388+49.77, R = 716.20’Lt, L = 807.85’ (11,400‘ prior) Sta. 3379+91.88, R = 1432.40’Rt, L = 707.92’ (10,600‘ prior) Sta. 3369+66.09, R = 2289.83’Lt, L = 1243.67’ (9,500‘ prior) Sta. 3356+52.15, R = 1432.40’Lt, L = 700.21’ (8,200‘ prior) Sta. 3348+23.73, R = 954.93’Rt, L = 934.17’ (7,400‘ prior) Sta. 3337+60.11, R = 1432.40’Lt, L = 1093.27’ (6,300‘ prior) Sta. 3329+30.84, R = 954.93’Rt, L = 525.40’ (5,500‘ prior) Sta. 3320+37.13, R = 716.20’Rt, L = 971.18’ (4,600‘ prior) Sta. 3310+61.13, R = 954.93’Lt, L = 940.83’ (3,600‘ prior) Sta. 3284+75.37, R = 954.93’Lt, L = 906.62’ (1,100‘ prior) **Sta. 3274+21.72 – Truck Escape Ramp** Sta. 3265+58.40, R = 2291.83’Rt, L = 550.00’ (900‘ after) Sta. 3256+82.58, R = 954.93’Lt, L = 997.78’ (1,700‘ after) Sta. 3245+72.13, R = 2291.83’Rt, L = 452.78’ (2,800‘ after) Sta. 3236+77.57, R = 954.93’Lt, L = 755.00’ (3,700‘ after) Sta. 3227+32.76, R = 954.93’Rt, L = 1034.63’ (4,700‘ after) Sta. 3206+28.54, R = 1909.86’Lt, L = 600.86’ (6,800‘ after) Sta. 3195+58.54, R = 1432.40’Rt, L = 1336.81’ (7,900‘ after) Sta. 3178+34.92, R = 1637.02’Lt, L = 2013.01’ (9,600‘ after) Sta. 3143+06.54, R = 2864.79’Lt, L = 1401.94’ (13,100‘ after) Sta. 3038+04.88, R = 5729.58’Rt, L = 2275.28’ (23,600‘ after)
Entering Vertical Geometry	Sta. 3423+00, -5.0000% (14,900’ prior) Sta. 3410+50, -0.3510% (13,600‘ prior) Sta. 3400+50, -7.9850% (12,600‘ prior) Sta. 3381+50, -3.4290% (10,700‘ prior) Sta. 3373+50, -7.1000% (9,900‘ prior) Sta. 3340+00, -4.0000% (6,600‘ prior) Sta. 3333+50, +1.1667% (5,900‘ prior) Sta. 3321+50, -8.0000% (4,700‘ prior) Sta. 3309+50, +1.5440% (3,500‘ prior) Sta. 3300+50, -6.6000% (2,600’ prior)

	Sta. 3274+21.72 – Truck Escape Ramp Sta. 3264+00, -8.0000% (1,000‘ after) Sta. 3233+00, -5.8571% (4,100‘ after) Sta. 3226+00, -6.0000% (4,800‘ after) Sta. 3208+00, -8.0000% (6,600‘ after) Sta. 3175+00, -6.0000% (9,900‘ after) Sta. 3154+50, -1.5135% (12,000’ after) Sta. 3136+00, +2.5000% (13,800‘ after) Sta. 3130+00, +0.7222% (14,400‘ after) Sta. 3112+00, -3.3889% (16,200‘ after) Sta. 3094+50, +0.8400% (18,000‘ after) Sta. 3082+00, -2.8333% (19,200‘ after) Sta. 3065+00, -3.8462% (20,900‘ after) Sta. 3052+00, -7.0000% (22,200‘ after) Sta. 3043+00, -2.5000% (23,100‘ after) Sta. 3035+00, -3.6153% (23,900‘ after) Sta. 3022+00, -3.0714%, (25,200‘ after)
Length of Mountain Grade Above	Greater than 14,900’ (2.82 mi)
Length of Mountain Grade Below	Greater than 25,200’ (4.77 mi)
Average Percent Grade of Mountain Above	-5.1447% over 14,900’ (2.82 mi)
Annual Average Daily Traffic (AADT)	1,609 (Year 2000)
Percent Trucks	10.1% (Year 2000)
Average Number of Accidents per Year	8.6 Total, 0.9 Tractor-Trailer
TER Usage Data Collected Between	01/19/1990 through 08/04/1993
Total Number of Uses	26
Total Number of Warranted Uses[1]	11
Conditions at Bottom of Grade	Unknown

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.20
State Route 77 SB TER – Typical Section

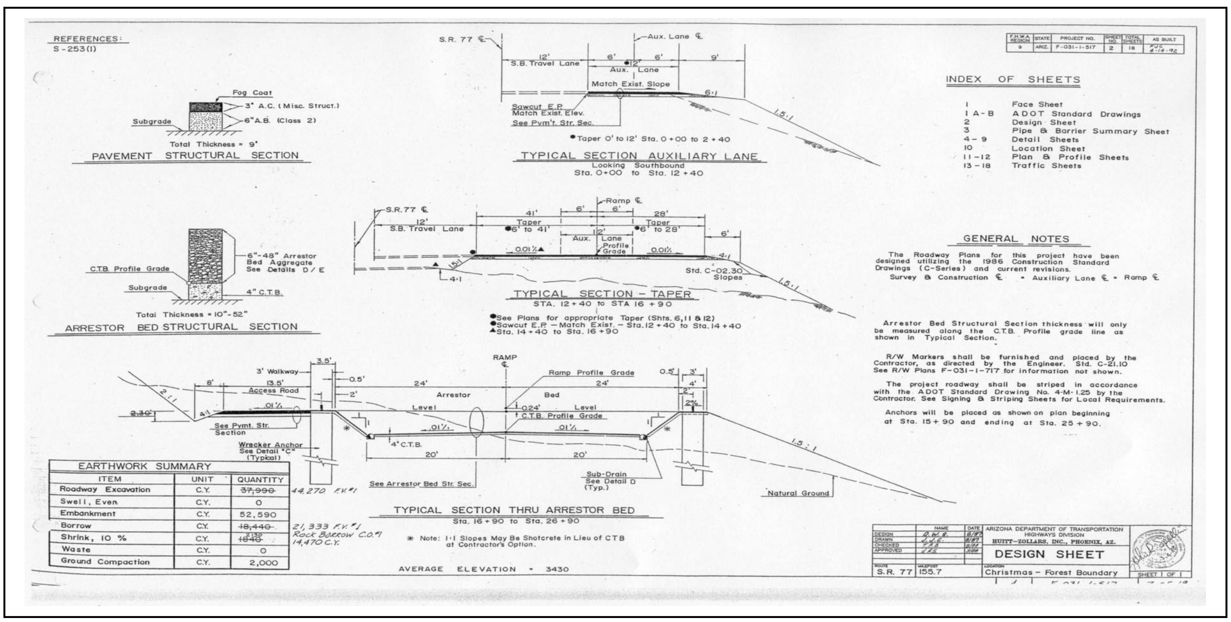


Figure 2.2.21
State Route 77 SB TER – Plan and Profile (1 of 2)

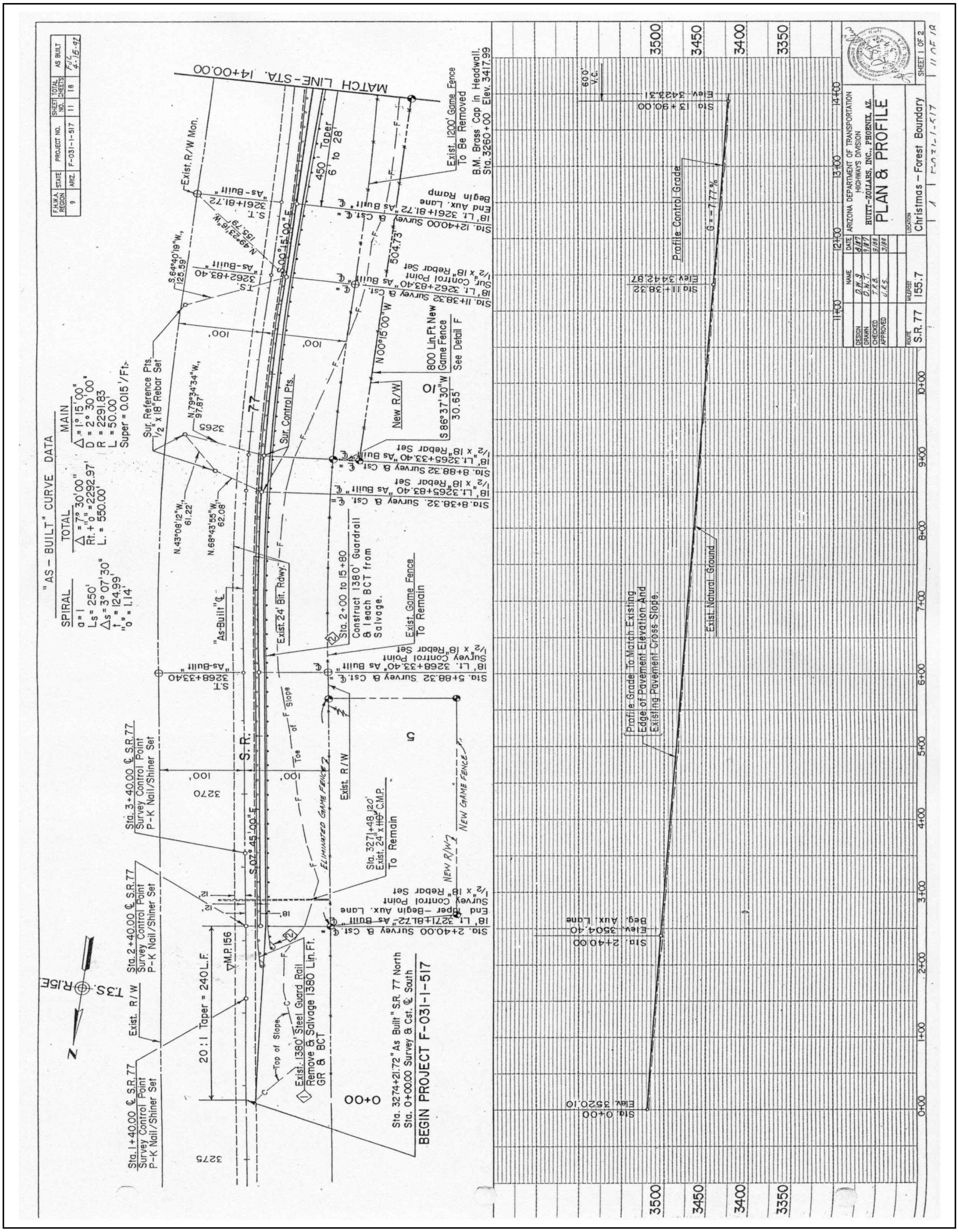


Figure 2.2.22
State Route 77 SB TER – Plan and Profile (2 of 2)

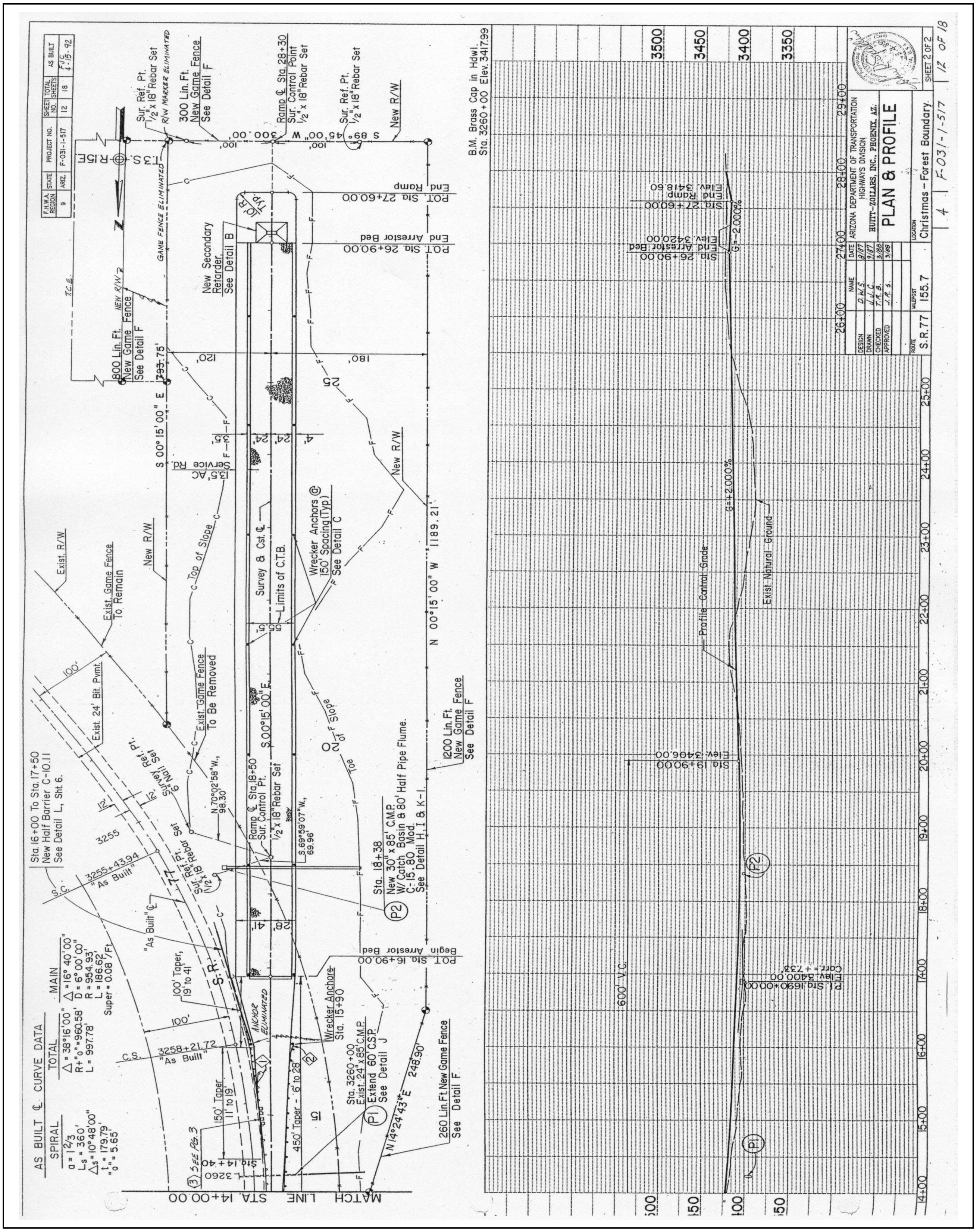


Table 2.2.8
US Route 60 WB TER

US Route 60 WB TER, US 60 MP 228	
Variable	**Description**
Mainline Station begin TER	97+31.82
Type of TER	Descending/Ascending Grade Arrester Bed
Exits	Right side of roadway
Length	1670 feet total length 680 feet exit ramp terminal 990 feet of arrester bed including secondary retarder
Width	Arrester bed width of 48 feet throughout
Anchors	Each side of ramp @ 150 foot intervals
Service Road	13.5 foot wide (not including anchors), paved, outside TER and roadway
Grade of TER	Varies from –5.707% to +2.000%
Aggregate (if any)	Unspecified
Depth of Aggregate	Tapers from 6” at entry to 48” in 150’, maintains 48” for final 840 feet.
Aggregate Liner	4” CTB
“Last Chance” device	48’W x 20’D x 6’H aggregate mound (1 ½:1 slopes)
Entering Horizontal Curve Data (Tangent sections not shown.)	Not Available
Entering Vertical Geometry	Not Available
Length of Mountain Grade Above	Not Available
Length of Mountain Grade Below	Not Available
Average Percent Grade of Mountain Above	Not Available
Annual Average Daily Traffic (AADT)	6500 (Year 2000)
Percent Trucks	5.7% (Year 2000, 19.0% Year 1996)
Average Number of Accidents per Year	37.4 Total, 3.6 Tractor-Trailer
TER Usage Data Collected Between	03/04/1990 through 06/01/2001
Total Number of Uses	50
Total Number of Warranted Uses[1]	23
Conditions at Bottom of Grade	Not Available

[1] Warranted uses include brake failure, overheating and/or smoking brakes, failure to downshift properly and loss of air pressure in braking mechanism.

Figure 2.2.23
US Route 60 WB TER – Typical Section

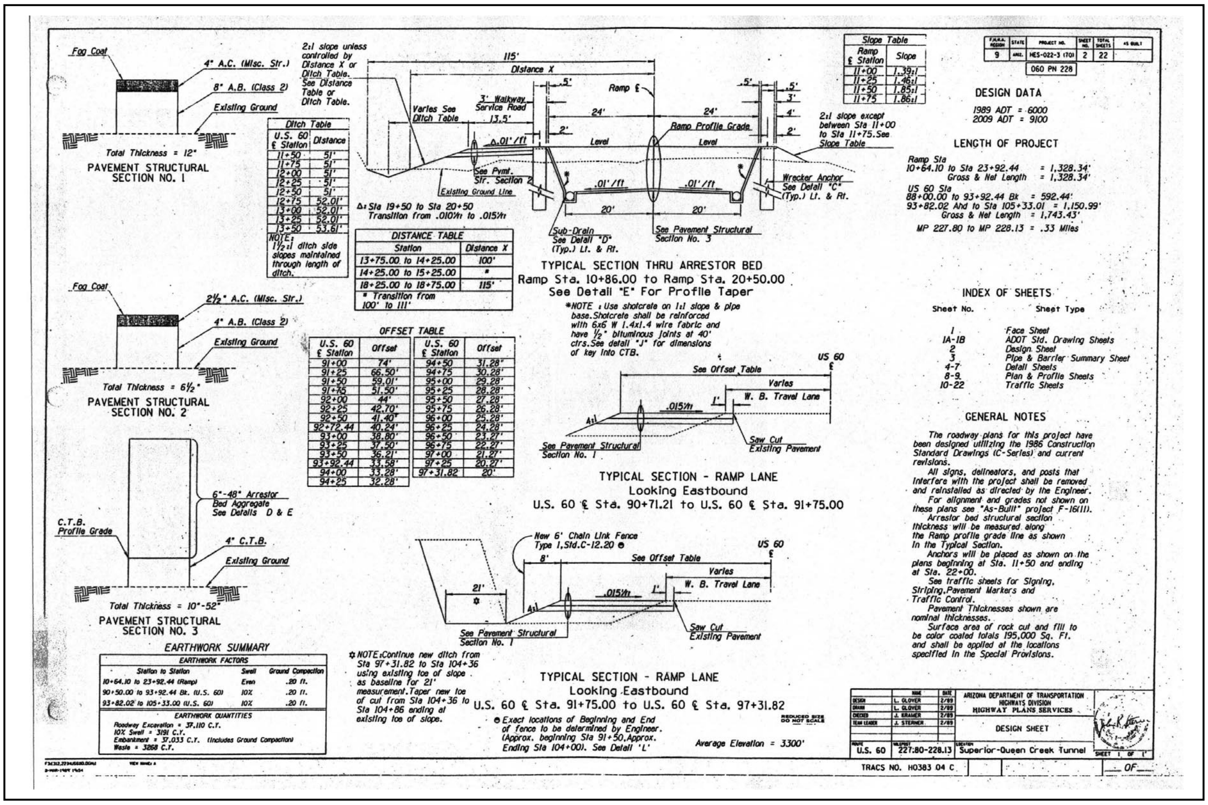


Figure 2.2.24
US Route 60 WB TER – Plan and Profile (1 of 2)

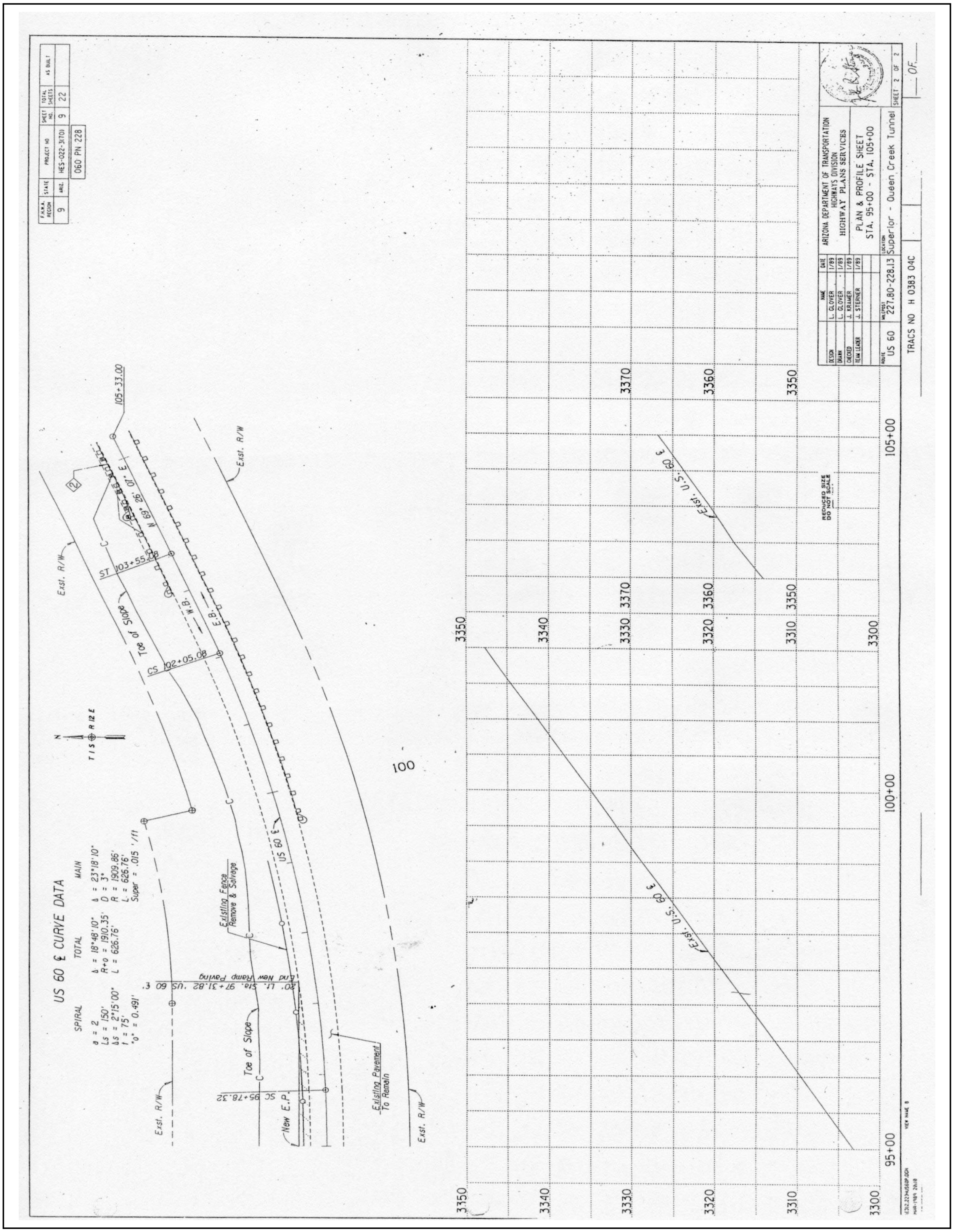
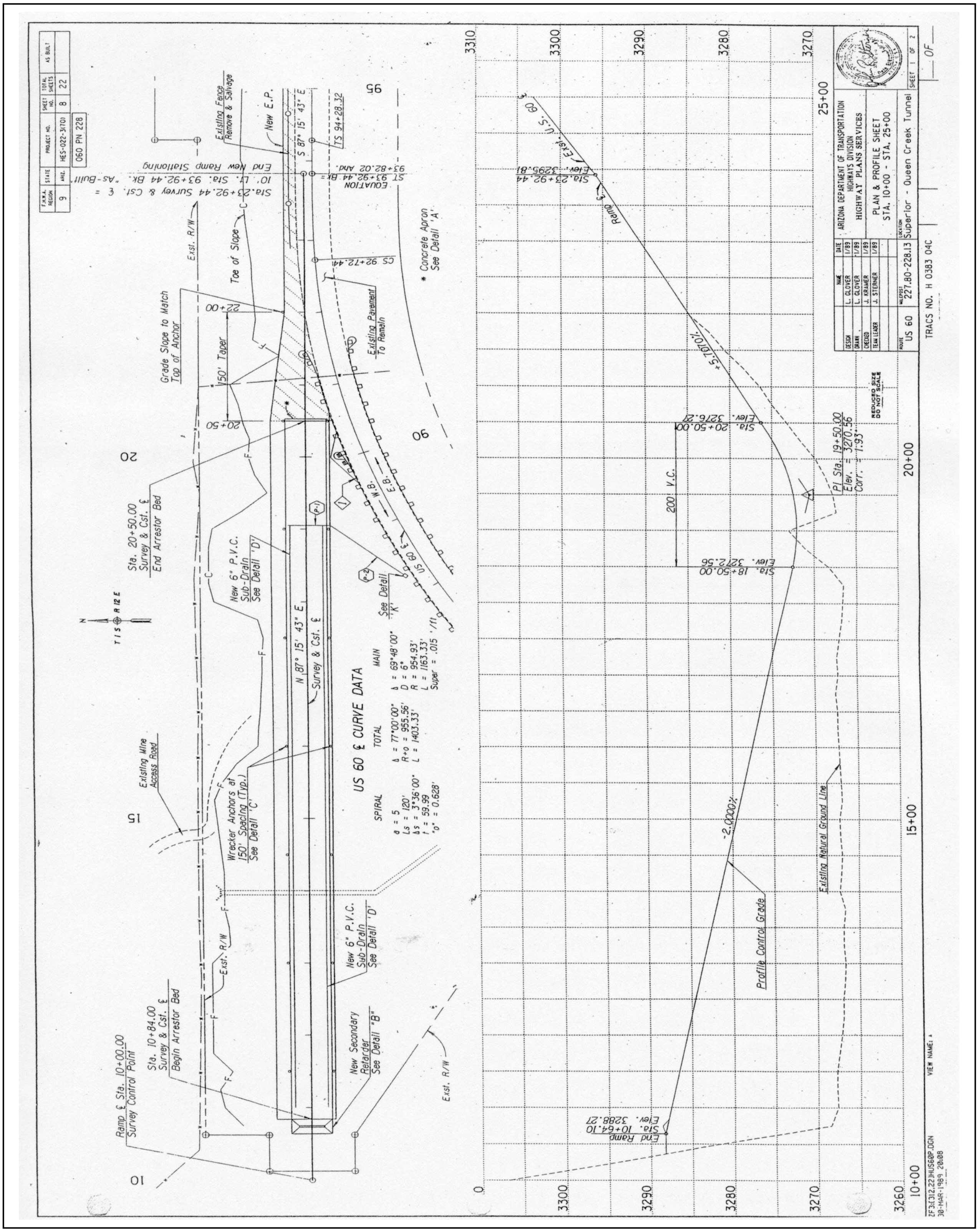


Figure 2.2.25
US Route 60 WB TER – Plan and Profile (2 of 2)



2.3 Photo Log Review

Photo logs supplying coverage of the areas in which truck escape ramps (TERs) currently exist were reviewed at the Transportation Planning Division (TPD), Data Section. The ADOT Photo Log provided information about advance signage, current TER conditions, and roadway conditions in advance and after TERs as well as concurrence with as-built plans.

The following ADOT Photo Logs were reviewed:

Table 2.3.1
ADOT Photo Log Inventory

Truck Escape Ramp Location	Photo Log #
Interstate Route 17 SB TER	D_99611
Interstate Route 17 NB TER	D_99907
US Route 89 WB TER	D_99605
State Route 68 EB TER (Both)	D_99703
State Route 77 SB TER (Both)	D_99401
US Route 60 WB TER	D_99403

2.4 Existing Truck Escape Ramp Data

Data on existing TERs was requested from the Intermodal Transportation Division (ITD), Traffic HES Section. The Traffic HES Section maintains a record system, which contains data on existing roadways, including TERs, within Arizona. Information including TER usage forms, previous studies and policies are contained in this record system.

The Truck Escape Ramp Usage forms, typically completed by Department of Public Safety (DPS) officers, identify information pertaining to the event. They typically include the date, time, weather condition, type of vehicle, vehicle and cargo weight, speed of entry, length of penetration into ramp, depth of penetration into gravel, condition of gravel bed, method of removal and reason for ramp use. While some forms were not completely filled out, most provided enough information to be useful for this study. The consistency with which these reports were completed is questionable. For example, US Route 60 had 26 reported usages (warranted and non-warranted) in 1990 compared with only 2 in 1992. It is probable that only a portion of the actual usages become logged on the TER Usage forms, which somewhat diminishes the reliability of the data.

The record system also contained Design Concept Reports and Project Assessment reports that were completed for existing and previously proposed TERs within the State. The reports were useful in determining what factors were considered in the determination of need and location, as well as what design parameters were used.

Additionally, ADOT prepared several technical reports for TERs in the 1980's and 1990's. The reports focused on highway downgrades and truck escape ramp policies.

The record system also contained information about the US Route 60 TER, including as-built plans, which were not on record with the ADOT Engineering Records. The plans were used to partially complete the tables in Section 2.2 and to provide additional information about this specific TER.

A majority of the information contained in the record, including previous policy and recommendations, was used to develop and support recommendations presented in Chapter 3, *Documenting the State of the Practice*.

2.5 Crash Data

Crash data supplying coverage of the areas in which TERs currently exist have been requested from the Intermodal Transportation Division (ITD), Traffic Records Section (Jim Williams – primary contact). In total, seven (7) locations were requested, representing the TERs tabulated in Section 2.2 (US 60 WB MP 228.1 was not included).

Crash data was requested for the entire mountain downgrade on which the TER exists. If the length of the downgrade was not known, the crash data was requested 4.0 miles prior and 4.0 miles after the location of the TER.

The crash was analyzed to determine if the existing TERs are reducing runaway truck accidents, to assess whether the TERs are located in the appropriate spot, and what the relationship is between percent grade, horizontal alignment and truck crashes.

2.6 Conclusions

Since the initial construction of truck escape ramps (TERs) began in Arizona in September 1982, the Arizona Department of Transportation (ADOT) has eight TERs throughout the State, as shown above in **Table 2.1.1**. While the specifics of each TER vary depending on the specific site and terrain, several variables are constant throughout. Every TER constructed by ADOT is of the arrester bed design, with a majority being on descending grade (non-gravity). Additionally, every TER is equipped with wrecker anchors and a service road for removal and maintenance purposes, along with a "Last Chance" device in the form of an aggregate mound.

An additional TER located along eastbound SR 80 has also been identified, although there are no records relating it to an ADOT sponsored project. It is believed that a mining company in the area constructed this TER.

A review of the information above found that almost all TERs were constructed on the lower half of the downgrade. Slopes on downgrades with TERs ranged from –4.6% to –6.0%, sometimes lengths exceeding 10½ miles. A comprehensive evaluation of TERs in Arizona, published source in 1991 by ADOT reached the following conclusions:

> "*All six (SR 77 SB MP 154.2 was not yet constructed) truck escape ramps in Arizona have proven to be effective in stopping out-of-control vehicles. There have been 70 reported uses of the ramps, which resulted in only three minor injuries, not considering the Bullhead City ramp prior to modification. The 70 uses of the ramps probably prevented 70 accidents, which could have resulted in costly property damage, serious injuries, and/or fatalities*."
>
> *"Truck escape ramps have proven to be useful countermeasures for reducing the severity of runaway truck accidents in Arizona."*

A review of the as-built plans shows that design standards for the arrester bed are inconsistent. For example, some widths are as great as 48 feet; others taper to as little as 26 feet. Additionally, some have aggregate depths of 48 inches, while others only 24 inches. For this reason, the development of better TER standards including the determination of need, site location and design parameters may be beneficial. The primary goal of the TER's on Arizona State highways is that they provide an important function for out-of-control runaway vehicles at locations to reduce the loss of life and property damage.

Chapter 3
Documenting the State of the Practice

3.1 Research Process

The primary intent of this chapter is to research policies and procedures that have already been established through Federal agencies, State agencies and technical societies and publications with regard to truck escape ramps (TERs). Once this information is known, it will better allow the Arizona Department of Transportation (ADOT) to understand the criteria for the evaluation of need, location and design of TERs used throughout the country.

The research process was broken up into four separate areas of concentration; Internet material, Federal agencies, State agencies and professional societies and publications. While it is understood and widely accepted that there exist no clear standards for the location and design of TERs, a review of current practice will allow for a more uniform set of guidelines for use within the State.

Through the process, ADOT plans to compile the various criteria used to determine the need for and location of TERs. Federal agencies will likely provide the best data for basic design, while State agencies in mountainous regions will likely best provide information for the determination of location. Society publications will provide technical analysis to support the design and determination of location from the agencies above. Primary contacts were made with State Departments of Transportation (DOTs) including Nevada (NDOT), Colorado (CDOT) and California (Caltrans), and Federal agencies including the Federal Highway Administration (FHWA).

3.2 Current Practices and Standards

3.2.1 Internet Research

For the purposes of this study, the internet was primarily used as a tool to find what information is available on the subject matter, who has been producing work relevant to this project and where it can be located. The internet provided key insights into which State DOTs had guidelines on TERs, which society publications would best be searched for information and what venders across the world were touting as the latest state-of-the-art technology.

As a means for providing guidance on which states have guidelines on TERs, the Internet proved an excellent source, both in providing literature links as well as contacts, described in detail under **Section 3.2.4**.

Several websites were found that linked the web search to various trucking related sites. It is interesting to note that few of these sites provided any information regarding runaway trucks, TERs, or the proper technique for downhill braking. In fact, the sites that did mention downhill braking techniques refer to the old theory that has been rescinded, namely continuous application of the brakes as opposed to intermittent application as the preferred method. Today there is almost unanimous agreement that the proper way to brake on a downgrade is to intermittently apply all service brakes, reducing speed by 5 mph during each application. Virtually every website that did mention runaway trucks stated brake failure as the primary cause.

Many vender websites are currently promoting vehicle-arresting barriers or dragnets in combination with TERs as either a mechanism for additional safety or for use in situations were topography does not permit the full design length to be achieved (See **Figure 3.2.1**). The benefits to these systems include shorter distances than conventional gravel arrester bed ramps, no susceptibility to weather and minimal maintenance. One website noted that by using a series of nets, the dragnet system can withstand impacts of an 80,000 pound tractor-trailer at speeds up to 80 mph with minimal damage to the vehicle and a reduction in the possibility of load shift and jack knifing.

Figure 3.2.1
Dragnet Arresting Barriers (John Thomas, Inc.)

3.2.2 Federal Agencies

The two primary Federal agencies researched were the US Department of Transportation, Federal Highway Administration (FHWA) and the American Association of State Highway Transportation Officials (AASHTO).

Federal Highway Administration (FHWA)

The primary research reference published by FHWA is the Manual of Uniform Traffic Control Devices (MUTCD). While the MUTCD does not provide guidance on the need, location and design of TERs, it does provide guidance relative to signage for downgrades as well as TERs. Specifically, the MUTCD states that Hill (W7-1) (See **Figure 3.2.2**) and Grade (W7-3) (See **Figure 3.2.3**) signs should be used in advance of downgrades with the following conditions:

- 5% grade and more than 3,000 feet long
- 6% grade and more than 2,000 feet long
- 7% grade and more than 1,000 feet long
- 8% grade and more than 750 feet long
- 9% grade and more than 500 feet long

The MUTCD also recommends installation of these signs on steeper grades or where accident history or field observations indicate a need.

Figure 3.2.2
W7-1 Sign Series (MUTCD)

W7-1
30"x30"

W7-1b
30"x30"

To compliment the Hill and Grade signage above, the MUTCD also recommends supplemental plaques (W7-2 series) for emphasis or where special roadway characteristics exist. Where appropriate, mileage plaques (W7-3a or W7-3b) should be used at intervals of one mile, to provide additional information to vehicle operators (See **Figure 3.2.3**).

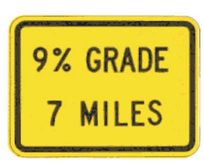
Where TERs exist or are being constructed, the MUTCD recommends the installation of W7-4 and W7-4a signage in advance of the ramp (See **Figure 3.2.4**). It notes that TERs are desirable for the safe deceleration and stopping of runaway vehicles on long downgrades, where installation of such ramps is practical. It further goes on to say that truck turnouts at the summit of the grade and special trucker information signs may be helpful in situations were TERs or steep downgrades are present.

Figure 3.2.3
W7-2 and W7-3 Sign Series (MUTCD)

W7-2b
24"x18"

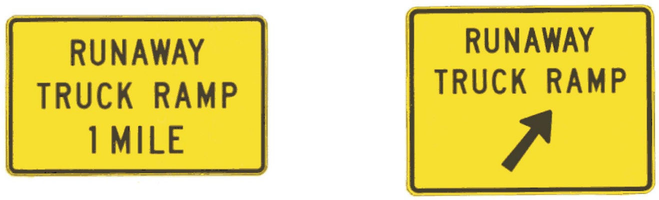
W7-3
24"x18"

W7-3a
24"x18"



W7-3b
24"x18"

Figure 3.2.4
W7-4 Sign Series (MUTCD)



W7-4
78”x48”

W7-4a
78”x60”

American Association of State Highway Transportation Officials (AASHTO)

The primary research reference published by AASHTO is A Policy on Geometric Design of Highways and Streets (Green Book). The Green Book provides general information on TERs as well as TER types and design considerations. The Green Book does state that specific guidelines for the design of TERs are lacking at this time.

The Green Book states that where long downgrades exist or where topographic and location controls require steep downgrades on new alignments, the installation of TERs at an appropriate location is recommended to slow and stop an out-of-control vehicle away from mainline traffic. An out-of-control vehicle is generally the result of loss of brakes either through overheating or mechanical failure, or failure to downshift at the appropriate time.

There are three primary resistance forces that act on every vehicle to affect its speed: engine, braking and tractive forces. For the purposes of TER design, engine and braking forces can be ignored, as TERs should be designed for a worse case scenario where the vehicle is in neutral and the braking system has failed. There are four subcategories under tractive resistance forces: inertial, aerodynamic (air), rolling and gradient. Inertial and negative gradient resistance forces act to maintain motion of the vehicle, while rolling, positive gradient and aerodynamic (air) resistance forces act to retard the vehicles motion. The two main forces that TERs attempt to control are rolling and gradient.

The Green Book recognizes three broad categories in which it classifies TERs: gravity, sandpile and arrester bed. The Green Book notes that the gravity TER has no means of preventing the runaway vehicle from rolling down the ramp and re-entering the mainline traffic. For this reason, gravity ramps are the least desirable escape ramp. The remaining two categories are further broken down into four basic types of TERs, which are currently in use: sandpile, descending grade, horizontal grade and ascending grade.

Sandpile	Composed of loose, dry sand, these ramps are usually less than 400 feet in length. The influence of gravity is dependent on the grade of the sandpile and the increase in rolling resistance is supplied by the loose sand.

Descending Grade	These ramps can be rather lengthy, as the gravitational effect is not acting to reduce the speed of the vehicle. The force of gravity acts in the direction of the vehicle and the increase in rolling resistance is supplied by an arresting bed composed of loose material.
Horizontal Grade	These ramps can also be rather lengthy, for the same reason as the descending grade. The force of gravity is zero and, similar to the descending grade, arrestor beds are used.
Ascending Grade	Use both the arresting bed and the effect of gravity, which in general reduces the ramp length necessary to stop the vehicle. The loose material acts to increase the rolling resistance while the force of gravity on the upgrade acts opposite to the vehicle movement.

The Green Book goes into considerable detail with regard to design considerations. It notes that the speed of out-of-control vehicles rarely exceeds 80 to 90 mph, which in turn should be the minimum entering design speed for TERs. The ramp should be designed to safely stop the largest vehicle that is expected to use the facility, which would generally be a WB-40 or WB-50. Furthermore, the selection of the TER is usually based on accident experience, with the highest attainable speed at that particular location being used as the minimum design speed for the ramp.

The Green Book states the following considerations for the design and construction of an effective TER:

1. To safely stop an out-of-control vehicle, the length of the ramp must be sufficient to dissipate the kinetic energy of the vehicle.
2. The width of the ramp should be sufficient to accommodate more than one vehicle. The minimum width is 26 feet, with a desirable width between 30 to 40 feet.
3. The surface material used in the arrester bed should be clean, not easily compacted, and have a high coefficient of rolling resistance. Aggregate should be rounded, single sized and as free from fines as possible. A positive means of draining the arrester bed should also be provided. Pea gravel is representative of the material used most frequently.
4. Arrester beds should be constructed with a minimum aggregate depth of 36 inches, with 42 inches recommended. To assist in decelerating the vehicle smoothly, the depth of the bed should taper from three inches at the point of entry to full depth in the initial 100 to 200 feet.
5. The entrance to the TER must be designed so that a vehicle traveling at high speeds can enter the ramp safely.
6. Signage of the ramp must be provided in advance with sufficient sight distance to allow the driver of an out-of-control vehicle time to react. Illumination of the approach and ramp is desirable.

AASHTO goes on to note that a surfaced service road, located adjacent to the ramp should be provided to allow access for the wrecker and maintenance vehicles. The width of this lane should be a minimum of 10 feet, with wrecker anchors spaced at 300-foot intervals.

The TER should exit to the right of the mainline, with an alignment tangent to the mainline or of very flat curvature. TERs should be provided wherever a need is determined, but unnecessary ramps should be avoided, meaning if a TER is provided prior to a sharp horizontal curve, another TER is not needed after the curve.

The Green Book states that the principal determinations as to the need for a TER should be the safety of the other traffic on the roadway, the operator of the out-of-control vehicle, and the residents along and at the bottom of the grade. To determine the distance required to bring an out-of-control vehicle to a stop with consideration given to the rolling resistance and gradient resistance, the following equation is recommended:

$$L = V^2 / [30(R \pm G)]$$

where: L = distance to stop (length of arrester bed), feet
V = entering velocity, mph
G = percent grade divided by 100; and
R = rolling resistance expressed as equivalent percent gradient divided by 100 (See **Table 3.2.1**).

Table 3.2.1
Rolling Resistance Based on Material Type

Surfacing Material	Rolling Resistance (lb/1000ob GVW)	Equivalent Grade (percent)[1]
Portland cement concrete	10	1.0
Asphalt concrete	12	1.2
Gravel, compacted	15	1.5
Earth, sandy, loose	37	3.7
Crushed aggregate, loose	50	5.0
Gravel, loose	100	10.0
Sand	150	15.0
Pea gravel	250	25.0

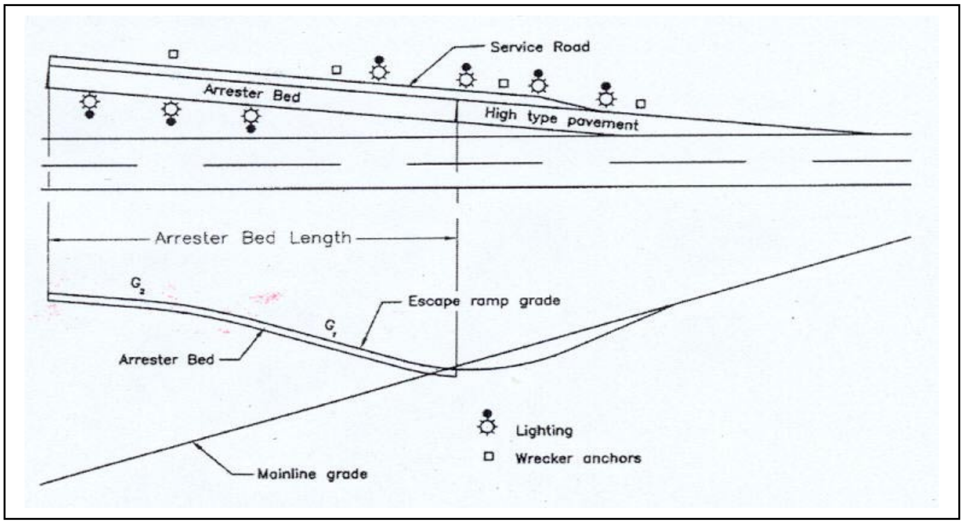
[1]Rolling Resistance expressed as equivalent gradient.

After each use, aggregate arrester beds should be smoothed and the aggregate loosened as necessary. Additionally, the bedding material should be cleaned of contaminants and loosened periodically to retain the retarding characteristics of the bedding material.

Where a full-length ramp is to be provided with full deceleration capability for the design speed, a “last chance” device should be considered when the consequences of leaving the end of the ramp are serious. Mounds of bedding material two to five feet high, with 1.5H:1V sideslopes, have been used in several instances.

The Green Book provides the following figure (See **Figure 3.2.5**) as reference for a typical TER.

Figure 3.2.5
Plan and Profile (AASHTO Figure 3-72)



Summary
Rather than providing specific guidelines for truck escape ramp (TER) need, location and design, Federal agencies have published recommendations, and in some cases minimums to be considered in TER development. Federal agencies recognize that on long downgrades, TERs may be needed where out-of-control vehicles (primarily caused by brake failure associated with overheating, mechanical failure or failure to downshift) could affect the safety of the general public.

The agencies recognize four types of TERs: sandpile, descending grade, horizontal grade and ascending grade, stating that which ever ramp is chosen, it should be sufficient in design to accommodate a WB-40 to WB-50 vehicle traveling at speeds of up to 90 mph.

The agencies note that the length of the ramp should be calculated taking into account velocity, percent grade and rolling resistance. A width of 26 feet is set as a minimum, with 30 to 40 feet being desirable. If an arrester bed is used, the material should be clean, not easily compacted, rounded and of one size with a high coefficient of friction. Pea gravel is sited as the most commonly used material. The aggregate depth should be a minimum of 36 inches, tapering from 3 inches at entry to maximum depth within 100 to 200 feet. Signage is referred to in detail as a necessary means of early warning to allow proper use of the TER.

Surfaced service roads are recommended adjacent to the TER for use by wreckers and maintenance vehicles. The minimum width should be 10 feet, with anchors spaced at 150 to 300-foot intervals. After each use the aggregate should be smoothed and loosened. “Last chance” devices should be considered in locations where the design length is not met or the consequences of leaving the ramp are serious.

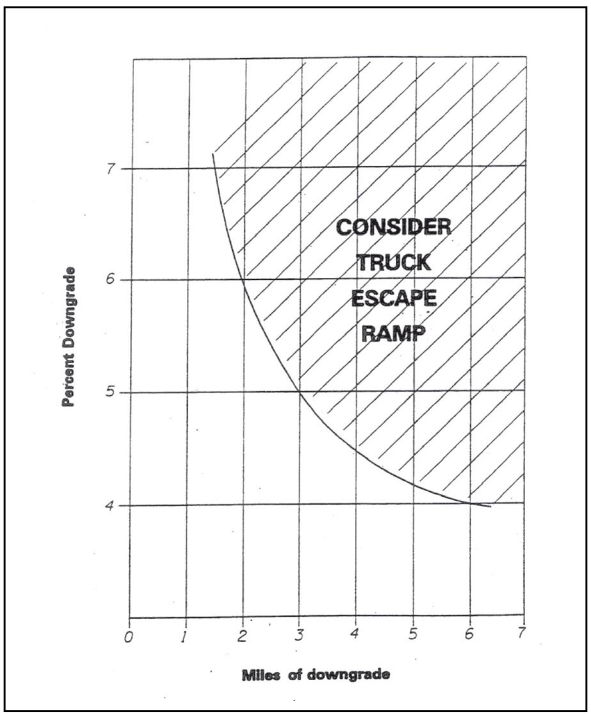
3.2.3 Arizona Department of Transportation

While the Arizona Department of Transportation's (ADOT's) *Roadway Design Guidelines* (1996) does not contain specific information on the determination of need, location and design standards for truck escape ramps (TERs), it does provide minimal guidance.

The guidelines indicate that there are two primary types of TERs: gravel arrester bed and gravity ramps. The guidelines also note that the gravity ramp is preferred over the arrester bed ramp due to its construction and maintenance costs, citing that Arizona does not have an ample supply of rounded gravel necessary for arrester bed construction.

ADOT states that the primary indicator of a runaway truck problem is a history of runaway truck accidents along sustained downgrades, usually near a horizontal curve. Hot and/or smoking brakes should be used as a secondary indicator. The graph below (See **Figure 3.2.6**) should be used to assess the need for a TER.

Figure 3.2.6
Determination of Need (ADOT Figure 209.4A)



The *Roadway Design Guidelines* state that experience has shown that ramps located three to four miles from the summit of the downgrade will intercept up to 80 percent of the runaway vehicles.

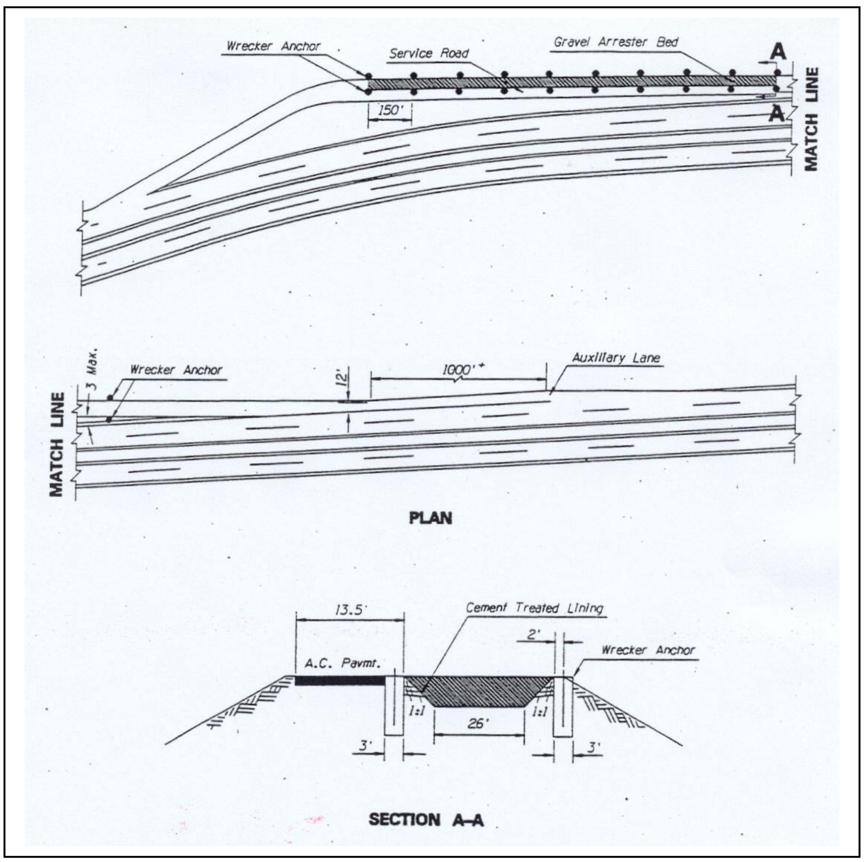
The guidelines offer little with respect to design standards, but does specify that the ramp should not be located on a curve, should be equipped with wrecker anchors spaced at intervals of 150 feet and the aggregate in the arrester bed should taper from an initial depth of six inches to a final depth of 48 inches within the first 150 feet. Additionally, the guidelines state that both arrester beds and gravity ramps should have service roads along the entire length of the ramp (See **Figure 3.2.7**).

The length of the escape ramp will vary depending on the specifics of the site, but should be calculated using the following equation:

$$L = V^2 / (30\ (R \pm G))$$

where: L = arrester bed length, feet
V = entering speed in mph, typically 90 mph
R = coefficient of rolling resistance (0.25 for pea gravel)
G = algebraic grade in percent

Figure 3.2.7
Plan and Typical Section (ADOT Figure 208.4B)



ADOT notes that brake check areas should be provided both as interim solutions while TER construction is being considered as well as after construction, to provide information pertinent to the downgrade, horizontal alignment and location of the TER.

Aside from the ADOT *Roadway Design Guidelines*, ADOT has also authored a number of technical reports, which chronicle the development of TER standards in Arizona and provide more specific guidelines and policies regarding TER need, location and design. The following provides a summary of these reports:

Emergency Truck Escape Ramp on US 60 East of Superior, January 1980

This technical report presents the proposal, including preliminary geometrics and signing, for a truck escape ramp (TER) on US 60 east of Superior and immediately west of the Queen Creek Tunnel. The proposal notes that due to topography, the TER was designed as a gravel arrester bed.

The location of the TER was determined by analyzing topographical features, existing roadway alignment and historical accident experience. The TER was placed in advance of geometrically restrictive areas further downgrade. The TER also takes advantage of a short tangent section of roadway.

The TER was designed with an entering design speed of 80 mph capable of accommodating a WB-50 vehicle. The TER has a zero percent grade and an arrester bed length of 950 feet, with an additional 350 feet on the exit ramp terminal. The report discusses the minimum sight distance required for the design speed and percent grade of the downgrade, indicating that cut sections will be required to achieve minimum sight distances.

The arrester bed material was designed for ¼ to ⅜ inch diameter pea gravel. Other materials, including blow sand, cinders and fly ash were considered for the arrester bed material, but were found to create excessive internal friction and thus would not be suitable arrester materials. The report notes that the arrester bed will need to be re-leveled and loosened after each use and that the gravel be loosened periodically to maintain design drainage and energy absorption characteristics. It states that the pea gravel may need to be cleaned or replaced over time.

For additional safety, the report calls for a sand berm at the end of the ramp for vehicles that may have overrun the ramp. Additionally, due to the large, steep fill sections, tri-beam guardrail should be installed on both sides of the TER to prevent vehicles from sliding down the fill slopes.

The report utilizes a different means of calculating the required length of the arrester bed, taking into account the aspects of physical mechanics. The end result is similar to that of the equation specified in the *Roadway Design Guidelines*.

Final Design Concept Report, Bitter Springs Jct. US 89 & US 89A, Emergency Truck Escape Ramp, February 1982

The Final Design Concept Report (DCR) for the US 89A TER was prepared primarily due to accident history and the potential for runaway vehicles to not be able to stop, as required at the time, at the intersection of US 89 and US 89A. At the time of this report, US 89 created a Tee-intersection with US 89A, at which, US 89 was required to stop. (Since then, the intersection has been reconfigured, allowing US 89 the through movement and requiring southbound US 89A to stop.) Over a 3½-year period, 51 accidents were reported. One of these 51, and six others that were not reported, involved truck combinations that failed to stop at the intersection.

The TER was designed to accommodate a design speed of 85 mph and is located on a tangent section. The length of the TER is to be approximately 1700 feet (total length). A service road was constructed away from the through roadway for wreckers to assist embedded trucks. The end of the TER reconnected with the mainline movement of US 89A. Wrecker anchors were planned on both sides of the ramp every 300 feet. Advance signing will notify truckers and other roadway traffic of the approaching TER.

Design Concept Report, I-17 NB Truck Escape Ramp, December 1984
The Final Design Concept Report (DCR) for the I-17 northbound TER considered providing a truck escape ramp near milepost 283 to increase the efficiency and safety of the existing highway. Located along the rim of Copper Canyon, the DCR called for a TER to be constructed in the median of the interstate.

The TER design consisted of an aggregate depth of 24 inches. Pea gravel was used as the arresting material. A paved service road was used adjacent to the TER to allow wreckers and maintenance vehicles easy access. Wrecker anchors were spaced along the service road at 300-foot intervals. Prior to the downgrade, a brake check area some 250 feet long and 45 feet wide was constructed at the summit (MP 280.4). Signing was provided for both the brake check area and TER.

Aside from accident history, three other factors were considered when determining the proper location of the TER, including calculations of the physics of runaway vehicles, interview with the Department of Public Safety (DPS) and interview with truck drivers at the site.

Calculations involving the physics of runaway vehicles yielded speed-distance diagrams from which the overturning and sliding velocities of an 80,000-pound truck were calculated. Interviews with truck drivers at the existing brake check area indicated that a TER on the left side of the mainline is acceptable so long as high traffic volumes do not exist.

The TER consists of both descending and ascending grades, ranging from –4.58% to +2.00%. A gravel attenuator berm is provided at the end of the arrester bed, composed of pea gravel. The width of the arrester bed tapers from 40 feet at the point of entry to 26 feet in the first 400 feet.

Truck Emergency Escape Ramps, August 1985
Prior to the development of this policy report, two accidents occurred on Arizona highways that involved runaway trucks. The two accidents resulted in a total of 10 fatalities, prompting more detailed investigations into truck escape ramps (TERs). This policy report includes discussion of what TERs are, where they should be located, studies that have been previously completed and where TERs exist or are planned.

The policy report describes TERs as areas to the side of a highway that provide a means to slow and stop an out-of-control vehicle. There are four types of TERs considered in this report, including sandpile, ascending grade, horizontal grade and descending grade. The main forces that act to slow the out-of-control vehicle are gravity (sandpile and ascending grade) and rolling resistance (all four).

The policy report notes that there are no nationally adopted guidelines for the development of TERs, and that States are largely on their own to develop standards specific to their geography. The following thirteen guidelines were developed for TERs in Arizona:

1. Establish a brake check area immediately preceding the crest of the downgrade.
2. Locate the ramp in an area where a runaway truck can exit the roadway on a tangent and desirably provide a positive grade for the escape ramp.
3. If a location cannot be found with a positive grade, the negative grade should be decreased as much as possible.
4. Access to the ramp must be well marked in accordance with the MUTCD and should be designed for an entrance speed of 90 mph.
5. Pave the throat of the ramp plus sufficient distance to allow all wheels to leave the mainline roadway pavement prior to entering the arrester bed.
6. The arrester bed should be constructed with only round gravel ¼ inch to ⅜ inch in diameter.
7. Adequate drainage must be provided to prevent ponding of water and minimize freezing during periods of cold weather.
8. To insure that a vehicle utilizing the ramp will not be stopped abruptly, the depth of the arrester bed should vary from 12 inches to 30 inches in the first 400 feet.
9. A barrier with a sand barrel energy attenuator should be placed at the end of the ramp.
10. The ramp should be 40 feet wide at the entrance point and narrow to 20 feet in the first 500 feet.
11. A service road should be constructed adjacent to the arrester bed and should be surfaced so that wreckers and maintenance vehicles may use it without becoming stuck. Wrecker anchors should be installed adjacent to the service road at a spacing of 300 feet.
12. The edge of the arrester bed shall be delineated with red delineators.
13. The following assumptions shall be used in determining the length of the ramp:
    a. Gross axle weight = 32,000 pounds
    b. Entrance speed = 90 mph
    c. Final speed = 0 mph
    d. Coefficient of rolling resistance = 0.25
    e. Grade = actual grade of ramp

The policy report states that ADOT follows AASHTO's recommendation that the need for a truck escape ramp (TER) is typically determined by analysis of accident data. Additionally, the report notes that most of the accidents involving runaway vehicles occur on grades exceeding five percent over a distance exceeding two miles.

The policy report noted that at the time of publication, there were only three truck escape ramps (TERs) in the state, with an additional one under construction. Additionally, there are over 100 locations that have grade warning signs and 16 locations where there are pullout areas for brake checks.

The report concludes that ADOT has done a good job of analyzing accident data and installing TERs, grade warning signs and brake check areas where needed. It recommends that the study be updated to reflect current accident data. An inventory of locations where grades are five percent of more for a distance greater than two miles should also be included. If locations exist with high accident rates in these areas, TER evaluations should be considered.

Assessment of Heavy Vehicle Accidents on Highway Downgrades, October 1985

This report notes that on long steep downgrades, the possibility of runaway trucks due to brake failure, driver error, mechanical failure or some combination of the above, it a problem on Arizona highways. The report notes that in the absence of national standards for TERs, the thirteen design guidelines presented in *Truck Emergency Escape Ramps, August 1985* (above) should be used.

This report goes further than the previous in laying out a manner by which to determine whether or not a truck escape ramp (TER) is economically warranted. The methodology presented in this report utilizes a net present worth approach. The present worth of benefits assigns a dollar amount to the reduction in accident rates attributed to the TER. The present worth of the costs consists of construction costs plus periodic maintenance costs. Calculations resulting in the net present worth being greater than zero are considered economically desirable, with the larger the number representing the more desirable the improvement. The following steps should be taken:

1. Collect geometric design, environmental and accident data.
2. Identify feasible escape facility design types.
3. Calculate preliminary construction and maintenance costs for each feasible design type identified in Step #2.
4. Calculate present worth of costs for each escape ramp type identified in Step #2.
5. Calculate present worth of accident costs (benefits) for each downgrade over the life of the proposed improvement.
6. Compare the present worth of costs (PWC) with the present worth of benefits (PWB). If PWC **is** greater than PWB, go to Step #11. If PWC **is not** greater than PWB then the downgrade should receive further evaluation.
7. Identify and select potential ramp locations using either (or both) method: accident diagram plotted for the downgrade, cumulative degree of curvature plot for the downgrade.
8. Select escape ramp design type for each potential ramp location and calculate present worth of costs for each ramp location.
9. Calculate reduction in vehicle accident rate and present worth of accident costs (benefits) for each potential site.
10. Compare present worth of costs to benefits. If the net present benefit is positive the site is selected and recommended for construction of an escape ramp. If more than one site is positive, select the site with the greatest net present worth. If the net present benefits are negative than go to Step #11.
11. Check for special conditions such as land use development. If still not warranted, then examine alternative measures such as improved warning signs, brake check areas or alternative truck routing.

The report notes that ADOT has limited experience with costs associated with TERs. Generally speaking, descending grade ramps will have the highest costs, some as high as $1.3M compared to the $0.8M for an ascending grade TER. Typical construction materials for TERs are as follows:

- Bituminous or Portland cement concrete pavement transition from through lanes to escape ramp
- Aggregate base course for transition pavement
- Shoulders for transition roadway
- Aggregate for escape ramp service road
- Pea gravel for arrester bed
- Wrecker anchors
- Reinforced concrete pipe for drainage
- Drainage inlets
- Fencing
- Clearing and grubbing of site
- Unclassified excavation
- Guardrail
- Signing

The report notes that after a period of time, the pea gravel arrester bed may become contaminated. At some point, it may become necessary to completely replace or clean the pea gravel.

Truck Escape Ramp Policy, January 1987

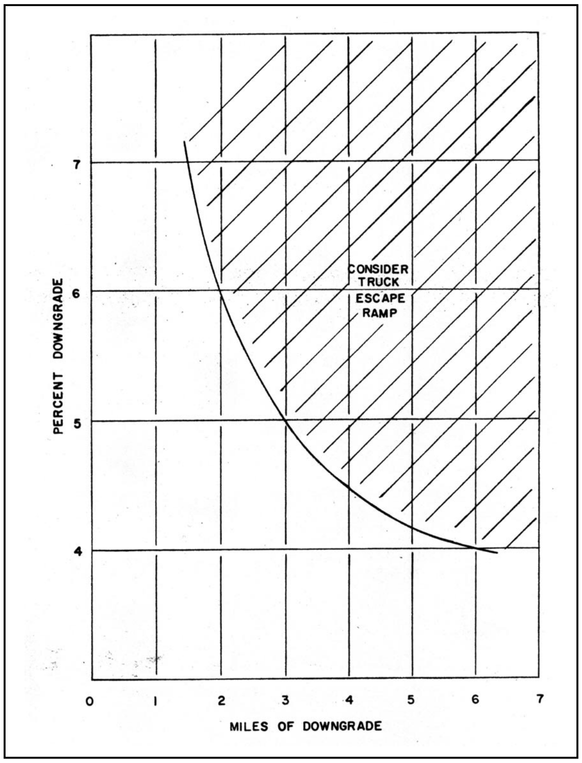
The Truck Escape Ramp Policy, written by the ADOT Traffic Engineering Section, provides the most complete policy within the State on the implementation and design of truck escape ramps (TERs) to date. The policy report not only discusses the determination of need and location, but also the design standards that should be used for the different types of truck escape ramps (TERs).

Three types of TERs are recognized by this report: gravity ramps, sand piles and gravel arrester beds. The report notes that based on previous national empirical studies and the ADOT experience with three gravel arrester bed TERs, ADOT has established the gravel arrester bed as its standards design for TERs. This is primarily because gravel arrester beds are the most flexible of the various types of TERs, they are free of topographical limitations, they offer larger drag forces than sandpiles and function effectively over a wide range of speeds.

The study notes that the primary indicator of need is the number of accidents that occur in conjunction with long sustained downgrades, usually near a horizontal curve. A secondary indicator of the need for a TER is the number of vehicles with hot and/or smoking brakes. Additionally, information regarding the need for a TER can also be pursued from professional truck drivers, wrecker operators, Department of Public Safety (DPS) Officers and by inspection of accident records.

When new facilities are in question, and there is no previous data to analyze, the graph below can be used (See **Figure 3.2.8**). Developed by Caltrans, the graph plots the relationship between percent downgrade and length of downgrade. If the new roadway combination yields a point to the right of the curve, further consideration should be given to a TER during initial design. The curve assumes that vehicles arrive at the summit with brakes at normal operating temperatures. If it is likely that vehicles will arrive at the summit with hot brakes, the curve should be adjusted to the left accordingly. Additional factors to consider are the volume and nature of the truck traffic.

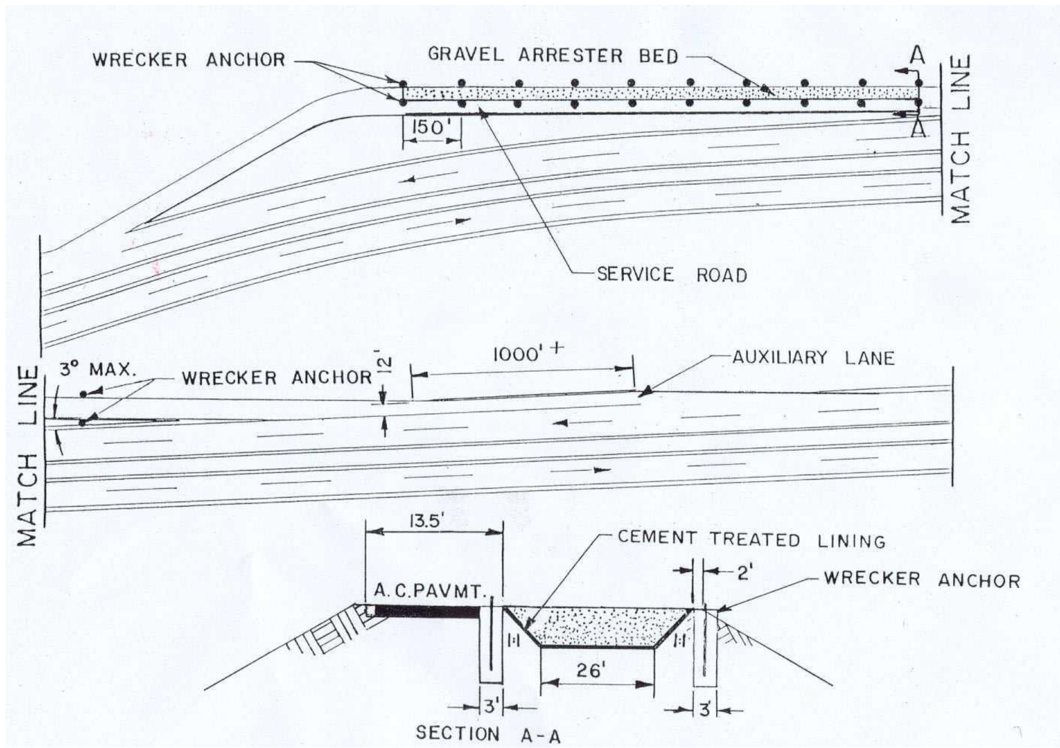
Figure 3.2.8
Relationship between Percent and Miles of Downgrade (ADOT)



Once the need for the TER has been determined, the next step is to determine the proper location. The location of TERs is largely controlled by topography. Typically, an escape ramp should only be considered on the lower half of a downgrade, and if at all possible, should be located on a tangent and not on a curve. TERs should normally be located on the right side of the roadway, although left side exits are permitted on divided highways.

In general, the approach to the ramp should be as simple as possible. The approach to the gravel arrester bed should be squared off so that all wheels on an axle enter the arrester bed at the same time. Whenever possible, sag and crest curves on the approach should be avoided, as this may lead to driver confusion. If possible, an auxiliary lane should be provided. When considered, the auxiliary lane should be a minimum of 1,000 feet long (See **Figure 3.2.9**).

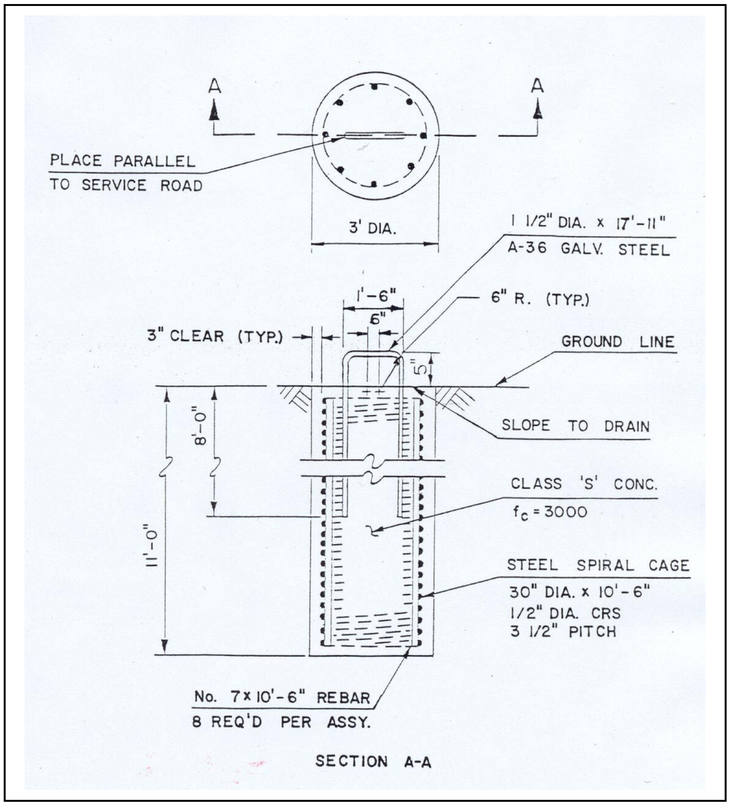
Figure 3.2.9
Desired Alignment for Truck Escape Ramp (ADOT)



The TER alignment should be on one continuous tangent. If an auxiliary lane is not used, the departure angle between the through movement and the TER should be as flat as possible, and capable of safely accommodating a vehicle traveling at the design speed (90 mph).

The policy notes that the arrester bed width of 26 feet generally will provide adequate maneuvering room. It also notes that this width will theoretically accommodate a second vehicle prior to the first being removed. A paved service road, normally on the same side of the TER as the highway, should be constructed with a minimum width of 13.5 feet. Whenever possible, it is desirable to have the service road return to the through movement. Along the edge of the service road and arrester bed, wrecker anchors should be spaced at 150-foot intervals along both sides of the arrester bed (See **Figure 3.2.10**). Additionally, anchors should also be placed in advance of the gravel bed approximately 150 feet.

Figure 3.2.10
Wrecker Anchor Detail (ADOT)



The primary theory behind the gravel arrester bed is that the vehicle will sink into the gravel, slowly bringing the out-of-control vehicle to a safe stop. To do this, the material must have a low bearing capacity and not be easily compacted; characteristics usually found in single-sized, well-rounded stream gravel. The aggregate used in the arrester bed shall be in compliance with ADOT Materials Specifications as shown in Table 3.2.2 below.

Fine materials are sited as one of the principal contaminants of arrester beds. Contamination can come from four main sources; existing ground, surface, vehicles and the gravel itself. Paving the bottom and sides of the arrester bed basin can control ground contamination. Contamination brought by the surface can be minimized by an adequate drainage system, providing good roadway drainage as well as arrester bed drainage. Contamination caused by vehicles entering the arrester bed is difficult to control, as they are usually unpreventable. And using high quality gravel can minimize contamination from the aggregate itself.

To minimize the need to remove and replace or wash the gravel, the policy states that it is desirable that the arrested bed be of sufficient depth to allow normal contamination, but still maintain the ability to retard and stop an out-of-control vehicle. Arrester beds shall gradually increase from an initial depth of six inches to a maximum depth of 48 inches in the first 150 feet. The surface of the arrester bed aggregate should be as smooth as possible with no humps or hollows (See **Table 3.2.2**).

Table 3.2.2
Materials Specification (ADOT)

Specification for Arrester Bed Aggregate		
Description:	The work shall include furnishing and placing arrester bed aggregate.	
Materials:	Aggregate for the arrester bed and secondary retarder material shall be clean, uncrushed, inert stone or gravel composed of naturally rounded screened particles free from lumps or balls of clay, calcareous or clay coating, caliche, synthetic materials, organic matter or other deleterious substances.	
The arrester bed and secondary retarder aggregate shall conform to the following requirements:		
	The gravel shall be washed.	
	Gradation – (ARIZ. 201b, Section 12(3))	
	Sieve Size	**1 Percent Passing**
	1 inch	100
	½ inch	0 – 5.0
	No. 200	0 – 2.0
	Abrasion – (AASHTO T 96) 500 Rev., Maximum 35%	
	Bulk Specific Gravity – (ARIZ 211b) Range 2.30 to 2.85	
	Water Absorption – (ARIZ 211b) 4% Maximum	
	Fractured Faces – (ARIZ 212) 10% Maximum	
	Flakiness Index (ARIZ 233b*) 7% Maximum	
*ARIZ 233b shall be modified as follows:		
1. Paragraph 2 (c) add 1" sieve.		
2. Table I: is revised to read:		
	Table I	
	Sieve Size	
Passing	**Retained**	**Weight, G**
1 inch	¾ inch	1,200
¾ inch	½ inch	1,000
½ inch	⅜ inch	700
⅜ inch	¼ inch	300
¼ inch	No. 4	200
No. 4	No. 8	100
3. Table II: is revised to read:		
	Table II	
	Size of Material	
Passing	**Retained**	**Slot Width, G**
1 inch	¾ inch	0.525
¾ inch	½ inch	0.375
½ inch	⅜ inch	0.263
⅜ inch	¼ inch	0.184
¼ inch	No. 4	0.131
No. 4	No. 8	0.084

The contractor is advised that special processing methods, including the use of slotted screens, may be necessary during production of this material in order to meet the gradation and flakiness index requirements. Potential sources should be thoroughly examined to assure that materials meet all requirements. No changes to these requirements will be authorized.

The policy states that roadway runoff should be channeled away from the arrester bed and not allowed to flow into the aggregate. It notes that water that does enter the arrester bed needs to be drained as quickly as possible. French drains, perforated pipes, slotted drains and sloping of the prepared base are typical methods used to properly drain arrester beds.

The specific length of the truck escape ramp (TER) will vary depending on the TER type, material used, entering speed, etc. In terms of length, the ideal TER would be on an ascending or positive grade. The more positive the grade, the shorter the ramp needs to be since additional gravitational forces would be working in the ramps favor. Since many parameters are unknown, the following equation is used to provide for a conservative ramp length:

$$L = V^2 / [30 (R \pm G)]$$

where: L = Distance to stop in feet (arrester bed length)
V = Entering speed in miles per hour
G = actual percent grade divided by 100
R = 0.25 assumed drag coefficient of friction

A 90 mph entry speed is the minimum that shall be used for design.

The policy identifies several aspects of traffic control as being key components of TER design. The policy states that the edge of the arrester bed shall be delineated with red delineators, spaced at 50-foot intervals, as shown in ADOT Standard Drawing 4-M-1.25 (See **Figure 3.2.11**). It also notes that while advance signing is usually site specific, the typical advance signing is presented in ADOT Standard Drawing 4-S-1.16 (See **Figure 3.2.12**) and is essential in notifying the driver of an out-of-control vehicle about the TER ahead. Similarly, striping is usually site specific, but typical pavement markings for TERs are included in ADOT Standard Drawing 4-M-1.25.

After each use, the policy notes that the arrester bed should be smoothed. It is essential that the arrester bed be maintained as soon as possible following the extraction of a vehicle to provide optimum conditions for the next use. Desirably this would happen within 24 hours. The gravel will need to be loosened from time to time to maintain the optimum properties for which it was selected. Ideally the equipment being used to maintain the TER would perform all or most of the work from the service road, and not in the gravel itself.

The final point made by the policy is that a brake check area should be provided prior to the summit of a downgrade on which there is a TER. The safety pullout should be designed and signed in accordance with ADOT Standard Drawing 4-S-1.06 (See **Figure 3.2.13**).

Figure 3.2.11
Standard Drawing 4-M-1.25 (ADOT)

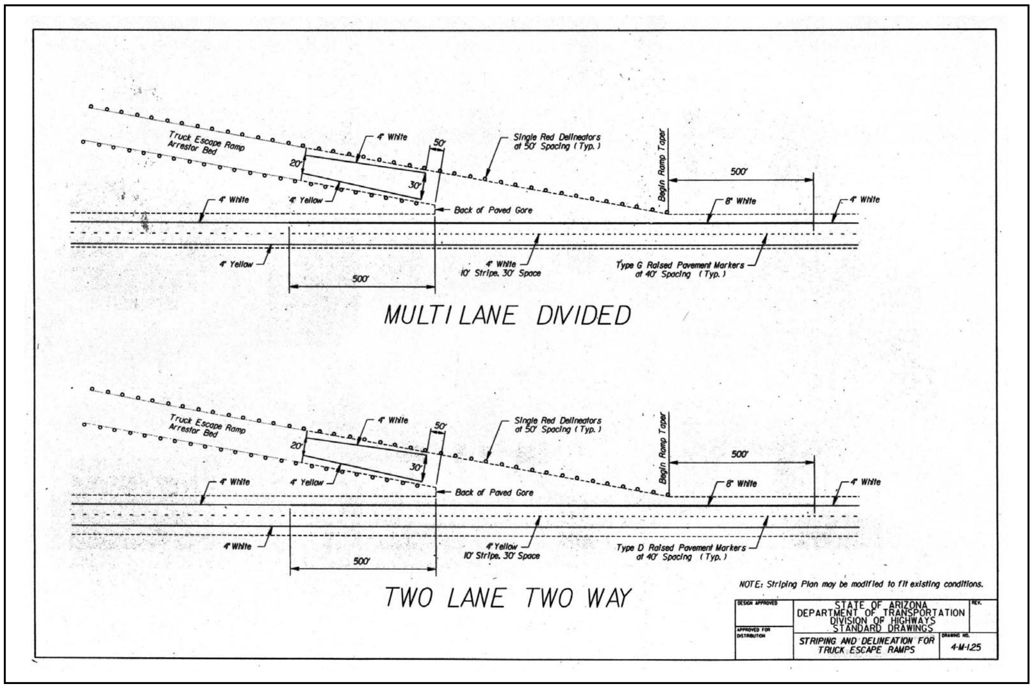


Figure 3.2.12
Standard Drawing 4-S-1.16 (ADOT)

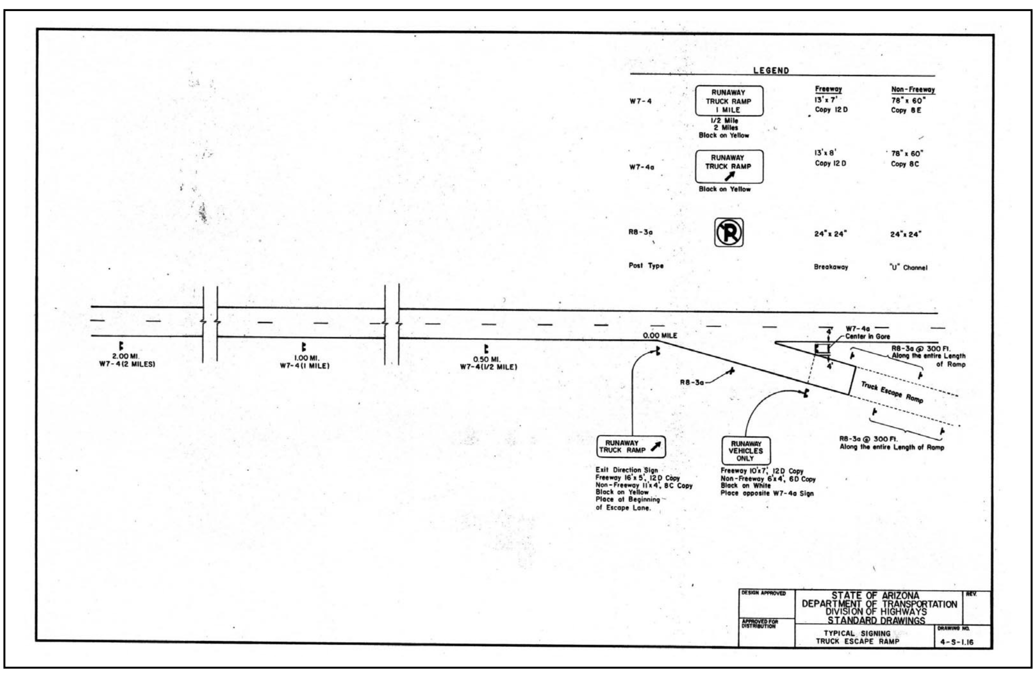
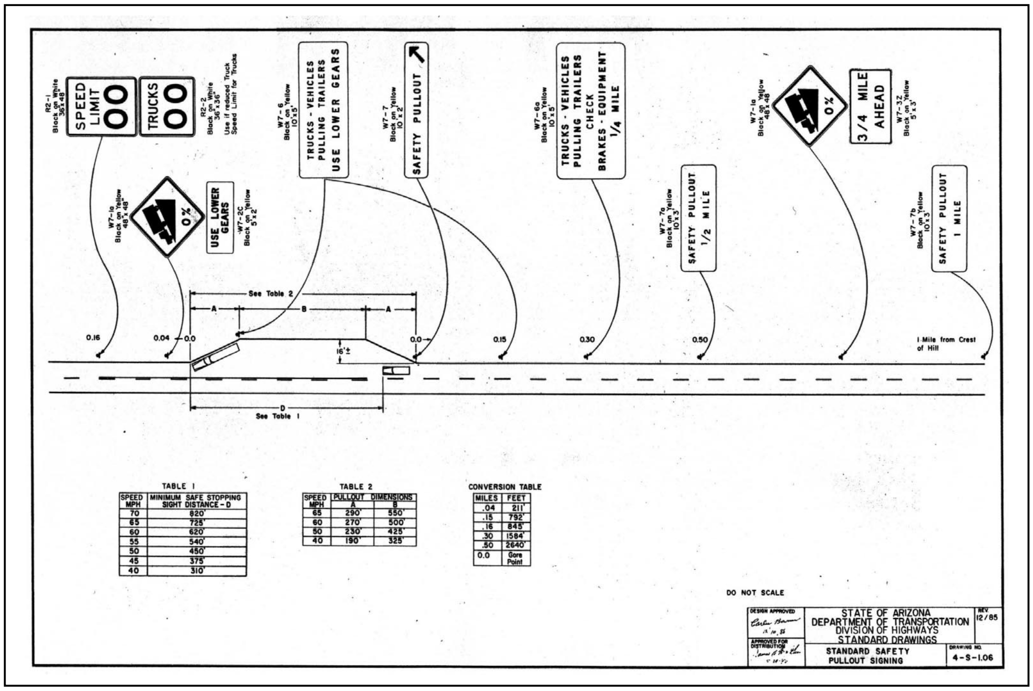


Figure 3.2.13
Standard Drawing 4-S-1.06 (ADOT)



Truck Escape Ramps in Arizona – A Comprehensive Evaluation, December 1991
The Comprehensive Evaluation prepared by ADOT in 1991 summarizes the characteristics of the six existing (1991) truck escape ramps (TERs) and evaluates the ramps' abilities to reduce the number of accidents associated with defective or overheated brakes. The study notes that out-of-control vehicles are typically the result of a driver losing control of their vehicle due to a loss of brakes either through brake overheating, mechanical failure, or failure to downshift at the appropriate time.

The report notes three types of truck escape ramps (TERs); gravity ramps, sand and gravel arrester beds, and a combination of both. The six TERs constructed between 1982 and 1990 by the Arizona Department of Transportation include I-17 NB (MP 283), I-17 SB (MP 300), US 60 WB (MP 228), SR 68 WB (MP 1), SR 77 SB (MP 155) and US 89 SB (MP 524). These TERs were considered in this evaluation.

The evaluation found that three of the TERs in Arizona are of the arrester bed type, and the other three are a combination of arrester bed and gravity. Additionally, of the 70 reported uses of the TERs, only three minor injuries were reported. A majority of the uses of the TERs have been by tractor-trailers. Other occurrences have included tanker trucks, smaller commercial vehicles, a motor home and passenger cars pulling trailers; all of which were out-of-control. The ramps were effective in bringing these vehicles to a safe stop.

Furthermore, four of the downgrades have shown a reduction in the number of accidents involving out-of-control vehicles after completion of the TERs. The signing for all six TERs either meets or exceeds the minimum presented in the MUTCD, Section 2C-26 and in the ADOT Truck Escape Ramp Policy (1987).

The evaluation concluded by stating that the truck escape ramps (TERs) have proven to be a useful countermeasure for reducing the severity of runaway truck accidents in Arizona.

Value Engineering Study, SR 177 Truck Escape Ramp, April 1994

In July 1993, a field review meeting was convened with the goal of developing a Project Assessment (PA) with feasibility and cost estimates for a truck escape ramp (TER) along State Route 177 near Ray Summit. A five-year accident history ending in December 1992 showed a total of 30 accidents occurred, 19 of which were "run off road". The more severe accidents occurred to the south of Ray Summit near milepost 159.6. The downgrade to the south of Ray Summit is at 10% for over one mile, culminating in a pair of severe reverse curves.

Three possible ramp locations were discussed. All three would require deep fills and steep side slopes, with one of the alternatives requiring the purchase of a residence.

The meeting concluded with a request for sketches and preliminary cost estimates for the three alternative locations discussed. It was also agreed that Ray Mine Complex, ASARCO would be contacted for their input of the need for and preferred location of an escape ramp.

In August 1993, a follow-up memorandum was transmitted to individuals who attended the July 1993 field review meeting to provide additional information as concluded prior. The memo identified borrow as the most significant expense for each of the alternatives considered.

The alternatives included:

Alternative 1	-	Arrester bed with a length of 900 feet on level grade and total length of 1100 feet. Requires approximately 949,000 cubic yards of fill, with an approximate cost of $3,406,600.
Alternative 2	-	Arrester bed with a length of 1200 feet on –5% grade and a total length of 2000 feet. Requires approximately 1,131,600 cubic yards of fill, with an approximate cost of $4,178,800.
Alternative 3	-	Total length of 1300 feet with compound grade beginning with –10% which decreases to –5% in 150 feet. Requires approximately 411,400 cubic yards of fill with an approximate cost of $2,545,900.

Alternatives 1 and 2 both depart just prior to the first curve, while Alternative 3 departs from the tangent section between the first and second curve.

ASARCO – Ray Mine Complex was contacted regarding the need for and location of TERs along SR 177. They did feel there was a need for a southbound ramp, and felt it would best be located between the two curves near milepost 159.6 (similar to Alternative 3). They noted that hauling firms typically have high turnover rates, and it is not unusual to have drivers who are unfamiliar with the roadway. They also noted that most drivers would attempt to successfully negotiate the first curve.

In September 1993, traffic accidents were analyzed in detail for the 10-year period between January 1982 and July 1993. Five accidents were reported on the four-mile grade from Ray Summit, which involved southbound vehicles with defective brakes. The analysis concluded that based on traffic accident data only, a truck escape ramp may be most beneficial to southbound vehicles just prior to the second curve.

Later in September 1993, following the traffic accident analysis, another memorandum was distributed providing a recommendation for which alternative to pursue. The memo noted that the segment of SR 177 between milepost 161 and milepost 159 is perceived by ADOT engineers as a high hazard area requiring remedial action, for which a Project Assessment was initiated to develop a truck escape ramp (TER).

In total, three alternatives were considered at a field review, with the critical issue being whether the TER should be before or after the first curve. To determine this point, the traffic accident analysis was reviewed. Four of the five accidents involved trucks traveling at high speed and/or without the use of their brakes. All four of these trucks were able to negotiate the first curve.

The range of vehicle speeds along the downgrade varied depending on start conditions and the effect of the braking mechanisms, ranging from 20 mph for a truck with fully functioning brakes to 95 mph for trucks with no retarding forces. Analysis indicates that trucks losing their brakes half way down the downgrade would be entering the first curve at speeds around 65 mph.

Based on the accident analysis and the speed calculations, it was recommended that Alternative 3, between the two curves, be developed.

In October 1993 another field review meeting occurred to develop a consensus recommendation on the location of the proposed TER. It was agreed that Alternative 3 would be pursued, with some sort of barrier to be included to prevent wreckers and pedestrians from accidentally going over the edge of the embankment.

In December 1993 the Initial Project Assessment (PA) was prepared. The initial focus of the PA was to determine the optimum location for the TER. The PA notes that the downgrade to the north of Ray Summit is at –10% but for only ½ mile, followed by flatter grades and mild horizontal curves. Thus, there does not appear to be a need for a TER in this location. The roadway south of Ray Summit also has a –10% downgrade, but for over 1 mile, followed by a pair of reverse curves. Discussion with local ADOT and mining staff indicate that the area between the two curves would be the ideal location for a TER.

Alternative 3 (from above) was selected as the recommended option because it is more likely to be used, as determined from the accident analysis. Additionally, Alternative 3 better complies with the standards presented in the ADOT *Truck Escape Ramp Policy* in terms of geometric design. Preliminary plans show the ramp will have an aggregate depth of 12 inches at the point of entry and taper down to 48 inches in the first 150 feet. The depth will remain at 48 inches throughout. The grade of the arrester bed will transition from –10% to –5% after the first 500 feet.

In April 1994 a Value Engineering Study was undertaken. The study recognized the following:

- Both horizontal and vertical geometrics in the study area are severe.
- The TER is warranted on ADT (truck) and alignment criteria, but not on number of accidents.
- The project has a high cost in comparison to other ramps.
- Earthwork accounted for 77% of the project cost.

The study also brainstormed ideas for reducing the cost of the ramp, as stated below:

- Re-evaluate ramp design speed.
- Provide better drag coefficient for arrester material.
- Limit the arrester bed length to 600 feet, providing crash barrels at the end.
- Don't provide adequate width for the trucks (26 feet maximum).
- Seek approval for lower design speed.
- Use geotextile in place of cement treated base.
- Reduce arrester bed depth to 36 inches from 48 inches.

The study concludes with the recommendation that the PA be put on hold pending determination of the project's priority based on cost.

Following the Value Engineering Study, in April 1994 the project was put on hold, based on the initial project assessment scope and project cost.

Candidate Location for an Operations and Safety Evaluation, US 60 MP 289.00 to MP 293.00, Salt River Canyon, November 1998

At the request of the Globe District, the Candidate Location for an Operations and Safety Evaluation (CLOSE Report) was conducted on US 60 through the Salt River Canyon. The report was targeted with three specific items for consideration: possible guardrail improvements, installation of a westbound passing lane and installation of an eastbound truck escape ramp (TER).

The report found that during a three-year period from May 1995 through April 1998 there were a total of 44 reported accidents on this section of highway. In total, 27 of the accidents involved vehicles that ran off the road, 15 of which were trucks. All but two of these accidents occurred north of the location that was initially considered for the TER.

The traffic accident data did not support the need for a TER at MP 290.80 as initially considered, but did support installation of a TER at MP 291.60. In addition to the TER, it was concluded that improved warning signage should be installed to encourage operators to use lower gears. A majority of the truck related accidents involved vehicles entering restrictive geometry in too high a gear. The report noted that the smell of hot brakes was ever-present during a field review at this location.

The initial location for the TER at MP 290.80 was rejected in favor of a TER located at MP 291.60. The primary reasons for this were:

1. Most of the truck related accidents occurred down the hill from the initially considered location.
2. The presence of several curves on the approach, which would limit sight distance to the ramp entrance.

The list below presents the factors for and against the installation of the TER at MP 290.8.

Support For:

- Most of the construction would take place off the roadway, minimizing traffic control and delays.

Support Against:

- The TER would be located too near the top of the downgrade.
- The TER would form a prolongation of the approach to the curve.
- The approach to the TER location is not on a tangent.
- There would be no way to provide a return for the service road.
- The proposed TER would cross two or three major drainages.
- New right-of-way would have to be acquired.
- There is no room to install an extended entrance to the TER, or an auxiliary lane on the approach.

The list below presents the factors for and against the installation of the TER at MP 291.6.

Support For:

- This location is just before the curve where the majority of truck run-off-road accidents have occurred.
- The TER would be located on a reasonably tangent section of roadway.
- Drainage modifications would probably be limited to extension of three culverts.
- This location would allow installation of a service road return.
- Little to no new right-of-way would have to be acquired.

Support Against:

- Most of the construction would take place in or immediately adjacent to the roadway.
- There is no room to install an extended entrance to the TER, or an auxiliary lane on the approach.

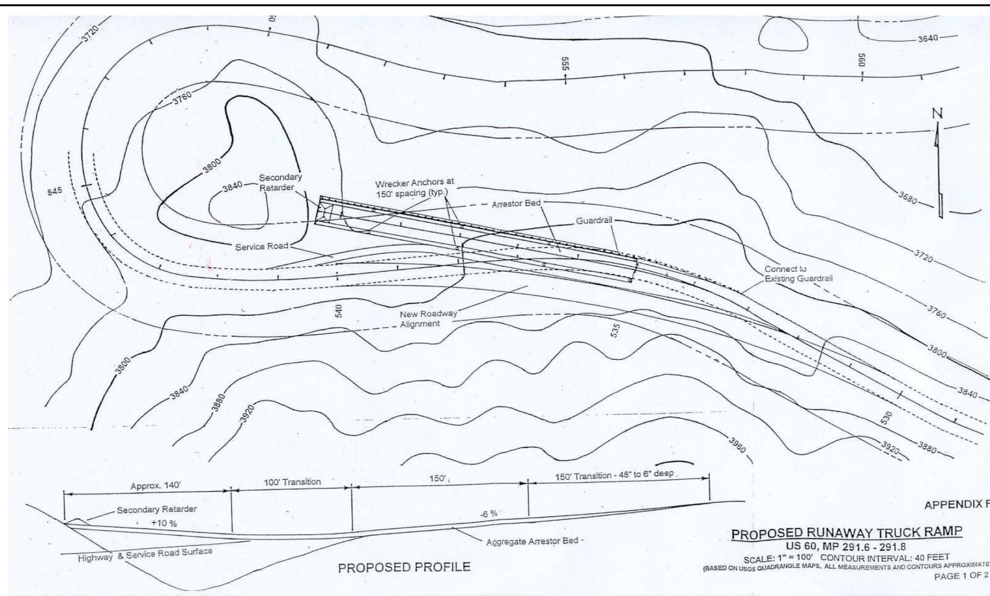
The report completes a benefit/cost ratio economic analysis to determine if the annual benefit in terms of accidents prevented outweighs the costs of constructing and maintaining the TER for its life (20 years). The report notes that the economic analysis of a TER is not as straightforward as most highway improvements. This is mainly because most highway improvements function without deliberate action taken on the part of the driver. TERs are different in that not only does the driver need to recognize that there is a problem, but they must also recognize the risk associated with not using the TER and take action to use the improvement.

The next steps are to determine accident reduction factors associated with the proposed TER and associated costs of each type of accident. Since it was perceived that a tractor-trailer would cause a greater deal of damage than passenger vehicles (the majority of accidents that make up the established accident costs), the values were all raised \$48,000, with the exception of “Fatal”, which remained unchanged.

Once the reduction factors and associated costs have been determined, an estimated construction cost for the new TER was developed. This cost was then broken into 20 years (project life), factoring in interest and annual maintenance costs. If the annual benefits (cost associated with money saved on accident reduction) are greater than the annual costs (cost to construct and maintain TER on a yearly basis), then construction of the TER is economically justified. The larger the ratio, the more justified the construction. With a benefit/cost ratio of 4.27, the TER along US 60 at MP 291.6 was considered to be cost effective and justified as a safety improvement.

The preliminary plans called for an ascending grade arrester bed TER, of length roughly 540 feet with an initial grade of –6% and a final grade of +10%. The aggregate would transition from an initial depth of six inches to a maximum depth of 48 inches in the first 150 feet, and maintain 48 inches for the final 390 feet. The arrester bed is 34 feet wide, with a 13.5-foot service road between the TER and the mainline, that reconnects with the through movement. Wrecker anchors are provided on both sides of the TER spaced 150 feet apart. The arrester bed basin is composted of 4” of CTB and has a cross slope of 1%. A “Last Chance” device is placed at the end of the arrester bed measuring 30’Wx20’Dx6’H (See **Figure 3.2.14**).

Figure 3.2.14
US Route 60 CLOSE Report Plan and Profile (ADOT)



Initial Project Assessment, US 60, Salt River Canyon Truck Ramp, August 2001
This Project Assessment (PA) is the result of the CLOSE Report discussed above.

The PA notes that the truck escape ramp (TER) will be designed in compliance with ADOT's Roadway Design Guidelines (1996) and Truck Escape Ramp Policy (1987). The TER will consist of a 34-foot arrester bed section, 13.5-foot service road, and two 4-foot walkways on each side of the arrester bed (See **Figure 3.2.15**). The TER will begin at approximately MP 290.80. Advance signing for the TER will be provided in accordance with ADOT Standard Drawing 4-S-1.16.

The PA states that the total length of the TER will consist of the 150-foot transition from six inches to 48 inches (arrester bed depth) along with the length determined utilizing the equation shown in ADOT's Roadway Design Guidelines, Section 209.4.

Although the guidelines require a minimum entering speed for a TER of 90 mph, the PA used 50 mph as the design speed, which was approved by the State Traffic Engineer during the scoping stage.

The total length of the TER presented in the PA is 610 feet, including approximately 140 feet for the ramp terminal, 450 feet for the arrester bed (including transition length) and 20 feet for the secondary retarder. The entering grade is –4.3113% and the final grade of the TER is +3.0000% (See **Figure 3.2.16**). The remaining dimensions reflect those of the CLOSE Report, with the exception of the arrester bed basin cross slope, which now is presented with a normal crown cross slope of 1%. The ramp has a preliminary cost estimate of $2,222,000.

Figure 3.2.15
US Route 60 Project Assessment (PA) Typical Section (ADOT)

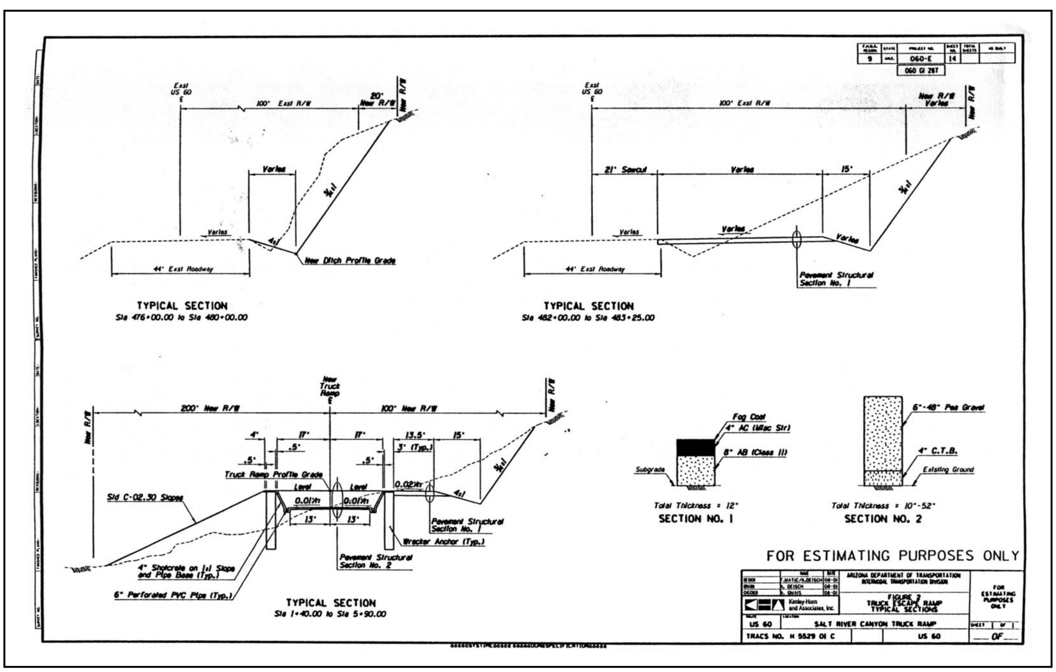
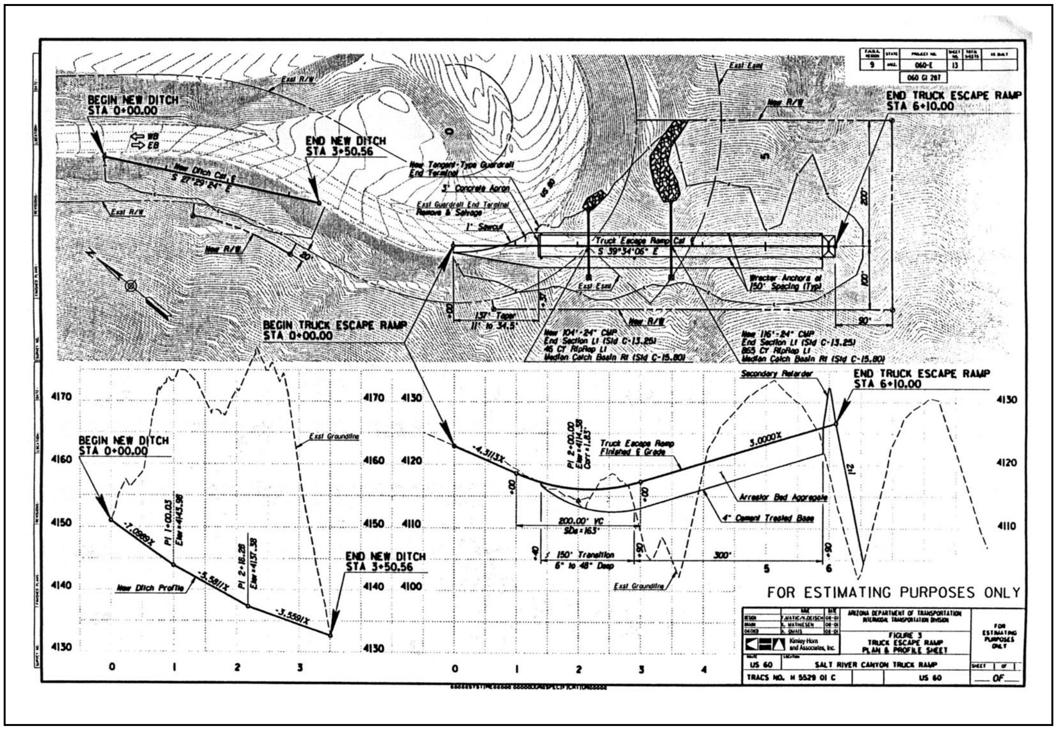


Figure 3.2.16
US Route 60 Project Assessment (PA) Plan and Profile (ADOT)



Summary

For over 20 years, the Arizona Department of Transportation (ADOT) has been studying the effects of constructing truck escape ramps (TERs) along sustained downgrades, as well as the parameters that go into TER design itself. From the first TER constructed in Arizona along US 89 in 1983 their value has been weighed not only by the amount of use the ramps get, but by the decrease in the number of truck related accidents on those downgrade; primarily the reduction of fatal accidents associated with runaway trucks.

Over the years, ADOT has fluctuated in many ways with its preferred design policies as they relate to TERs. Some information presented 20 years ago remains unchanged today, while other information, based on studies in state as well as around the country, has changed.

The determination of need for truck escape ramps (TERs) in Arizona is one area where the theory has not changed much over the past 20 years. The primary indicator of a runaway truck problem has always been the history of runaway truck accidents. Secondary indicators have changed slightly over the years, and include smoking/hot brakes, interviews with DPS Officers, professional truck drivers, wrecker operators and inspection of accident records. Occasionally it was observed that various documents also determined if the improvement was economically warranted to determine if the need was met.

The determination of location of the TER received a great deal less discussion over the past 20 years than did the determination of need. Current policy presented in the *Roadway Design Guidelines* states that TERs should be located on the lower half of a downgrade, where they can theoretically intercept up to 80% of the runaway vehicles. Several studies have indicated that the location of TERs is largely governed by topography. Additionally, reports have stated that existing roadway alignment and high accident locations also play a large part in the determination of location.

Many of the design standards used have changed over the years, with new concepts being added as theory and research on TERs increased. The *Roadway Design Guidelines* present the most recent policy on TER design. Prior to these guidelines, the 1987 publication *Truck Escape Ramp Policy* served as the principal reference. Fluctuations in design speed, preferred TER type, aggregate depth, TER width, service roads and wrecker anchors are noticeable from publication to publication.

The information published by ADOT will, in conjunction with information published by Federal agencies, assist a great deal in preparing up-to-date policy on TER need, location and design in Arizona.

3.2.4 Other State Agencies

As mountainous regions and steep downgrades exist outside of Arizona, other State DOTs were researched to determine what guidelines they use in the determination of location and need for TERs, as well as what design standards they impose. While States on both the east and west coasts of United States use TERs, States on the west coast were researched more heavily as they represent similar terrain, weather conditions and material types available. The following State agencies were researched:

- California Department of Transportation (Caltrans)
- Colorado Department of Transportation (CDOT)
- Montana Department of Transportation (MDT)
- Nevada Department of Transportation (NDOT)
- North Carolina Department of Transportation (NCDOT)
- South Dakota Department of Transportation (SDDOT)
- Utah Department of Transportation (UDOT)
- Washington State Department of Transportation (WSDOT)

California Department of Transportation (Caltrans)

The Caltrans *Highway Design Manual* does not specifically detail design criteria for truck escape ramps (TERs). The manual does refer to Traffic Bulletin No. 24 (1986), *Design Guide for Truck Escape Ramps*, which provides guidelines for location and design.

Bulletin No. 24 notes that several developments within the last 40 years have led to an increased number of runaway trucks on long, steep downgrades. First, the number of trucks on highways, and their average weight have increased. Additionally, an increase in competition and a reduction in profit margin may cause some truckers to reduce their overhead by reducing maintenance. Finally, in increase in out-of-state operators, who are unfamiliar with local terrain, is more common today than in years past.

The Bulletin recognizes two different types of TERs: gravity ramps and arrester bed ramps. It notes that gravity ramps are nothing more than an accessible surfaced side road on an ascending grade. They typically require little maintenance, and there is no need for special equipment to retrieve the vehicle. The possibility of rollbacks leading to jack knifing or re-entry of the vehicle to the mainline traffic is a potential problem. For this reason, gravity ramps are less desirable than arrester beds.

Arrester bed ramps vary in detail depending on the material used. The material can range from sand to 1½ inch aggregate. The grade of the arrester bed will also influence length, with ascending ramps providing greater stopping ability.

The primary indication of need, as expressed in the Bulletin, is the number or rate of incidents involving runaway vehicles. The presence of steep grades and/or sharp curves usually leads to these situations. A secondary indication is the relative number of trucks with excessively hot or smoking brakes.

The Bulletin recommends a sequential approach to resolve the runaway truck problem. The first step is to review the signage of the downgrade, making sure that appropriate curve and grade signs are provided, along with recommended downhill speeds. If the problem persists, a roadside brake check area at the summit is recommended. The brake check area allows drivers to check equipment, read about the upcoming downgrade and provides time for the braking systems to cool off. The final step is the installation of a TER. The Bulletin states that if none of these steps work to reduce the risk of runaway trucks, the downgrade can be restricted, and vehicles over a specified weight would not be permitted. It notes that this final approach is controversial.

Where a new highway is being constructed, there are no statistics to support the implementation of a TER. In this situation, the Bulletin recommends using the figure below (See **Figure 3.2.17**). If the combination of percent downgrade and length of percent downgrade fall to the right of the plot, a TER may be warranted, otherwise, a TER should not be considered unless special horizontal alignment conditions, such as sharp curves, exist.

The location of the TER, regardless of type, is largely dependant on terrain. The Bulletin does note that a ramp should only be considered on the lower half of the grade, as this is where most of the runaway situations would exist, and drivers would be more likely to utilize the ramps. The ramps should not be located on curves; rather they should be located along a tangent section of roadway.

When possible, the TER should have an auxiliary lane approaching the ramp. The lane should be posted for "Runaway Vehicles Only" and "No Stopping Anytime". They should be a minimum of 1,000 feet long. The approach to the arrester bed should be squared off, so all wheels of an axle enter the arresting material at the same time. The ramp should also be constructed so that the driver of the out-of-control vehicle can see the entire ramp from the auxiliary lane. The Bulletin notes that proper signing of the entrance to the TER is essential, and that lighting of the ramp entrance should be considered (See **Figure 3.2.18**).

The width of the ramp is dependant of the TER type selected. Gravity ramps, which do not contain the vehicle for an extended period of time, only require a width of 14 feet. While arrester beds, which may contain a vehicle for several hours, require a minimum width of 26 feet. The additional width of the arrester bed is to allow for multiple vehicles to use the ramp at the same time. A 12 to 14-foot service road should be provided adjacent to the TER on the mainline side for use by tow trucks and maintenance vehicles. The service road should be paved and shielded from mainline traffic so it is not mistaken for a shoulder or the TER itself. Anchors should be provided every 150 feet along the service road for use by tow trucks. Whenever possible, the service road should return to the mainline, to allow easy return of the tow truck and vehicle to the through roadway.

Figure 3.2.17
Guidelines for TER Need on New Highways (Caltrans)

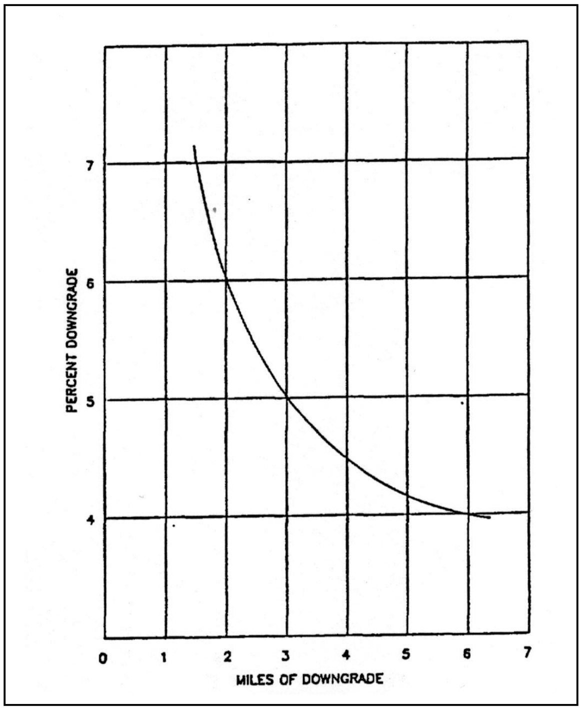
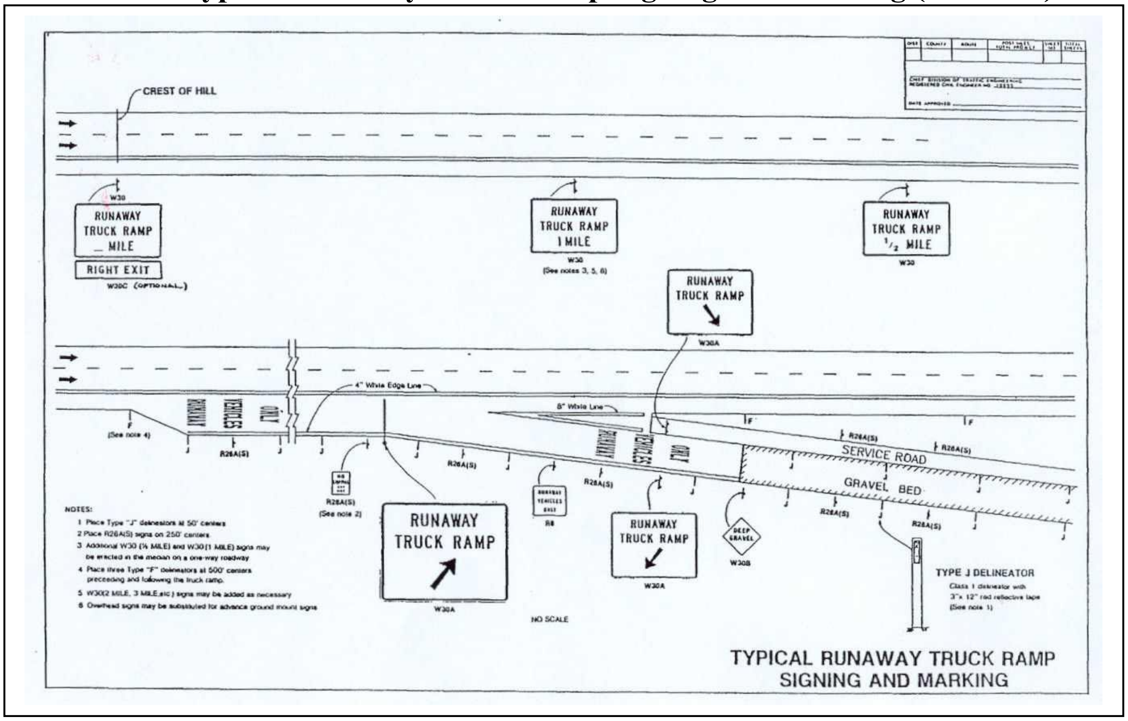


Figure 3.2.18
Typical Runaway Truck Ramp Signing and Marking (Caltrans)



The concept behind the arrester bed requires that the vehicle will sink into the arresting material, thereby slowing the vehicle to a stop. To do this, the material must be unstable and have a low bearing capacity. These properties are typically found in single graded, well-rounded stream gravel. The aggregate used in an arrester bed should be washed, free draining uncrushed gravel of uniform shape and size.

Fine materials are one of the principal contaminants of arrester beds. There are four main sources: ground, surface, vehicles and the gravel itself. Paving the sides and bottom of the arrester bed with either asphalt concrete, Portland cement concrete or a geotextile fabric, can reduce contamination from the ground. Providing a positive means of drainage surrounding the ramp, directing all roadway run-off from entering the arrester bed, can reduce surface contamination. Vehicles entering the ramp can contaminate the aggregate with fluids or load material. A positive means of draining the arrester bed and maintenance following each use will reduce these contaminants. The aggregate itself is the final contaminant, as over time it will weather and breakdown. For this reason, the aggregate will need to be replaced and/or reprocessed periodically.

Experience has shown that trucks will sink at least 12 inches into the arrester bed material. Additional experience has also shown that the lower 12 inches of material will typically become so contaminated and compacted that it will virtually act like cement treated base. For these reasons, the Bulletin recommends a minimum depth of material to be 36 inches, with 30 inches being an absolute minimum. The depth of the aggregate should taper from six inches at the beginning of the bed to maximum depth within 100 feet. This allows for gradual deceleration and reduces the risk of loadshift.

The Bulletin references the AASHTO Green Book for the formula to determine the desirable length of the escape ramp. The formula sited is:

$$L = V^2 / [30(R \pm G)]$$

where: L = distance to stop in feet
V = entering velocity, mph
R = rolling resistance expressed as percent gradient divided by 100
G = percent grade divided by 100

A 90 mph design speed should be the minimum speed used for most situations. As an additional safety factor, the Bulletin recommends extending the basic ramp length 25 percent.

Arrester beds should be as smooth as possible with no humps or hollows. If the full length of the arrester bed cannot be reached, it may be necessary to provide some attenuation towards the later part of the ramp. This can be accomplished with one or more mounds of arresting material across the full width of the arrester bed, or by the use of crash cushions. It should be noted that the use of crash cushions would likely increase the amount of fines entering the arrester bed. Proper signage should be used in advance of the ramp to notify runaway truck drivers and the traveling public of the presence of the TER. The approach and ramp should be delineated using Class 1 delineators with red reflective sheeting. Overhead signs, preferably illuminated, should be located prior to the ramp gore to better guide the runaway vehicle. (See **Figure 3.2.18** above.)

Another desirable feature at a TER location is a telephone. The telephone should be used by ramp users only, and thus should be hidden from view of the mainline traffic. Additionally, a message board (blank-out or changeable) should be located upgrade from the TER to notify other truck drivers if the TER is occupied or empty.

While gravity ramps require little maintenance, arrester beds require maintenance after every use, as the aggregate will require smoothing and decontamination. Additionally, the gravel should be loosened up or scarified after every ten uses or every six months, whichever is more frequent. If excessive fine material is noted, the aggregate will either need to be replaced or reprocessed.

Colorado Department of Transportation (CDOT)
The CDOT design manual does not contain a policy on the design of truck escape ramps (TERs), although TERs do exist within the state of Colorado. Similarly, CDOT does not have design standards for TERs.

Montana Department of Transportation (MDT)
The MDT design manual does not contain a policy on the design of truck escape ramps (TERs), although TERs do exist within the state of Montana. Sample plans of TERs constructed in the past are included below, (See **Figures 3.2.19 - 3.2.23**).

Figure 3.2.19
Montana Route 287 Truck Escape Ramp Typical Section (MDT)

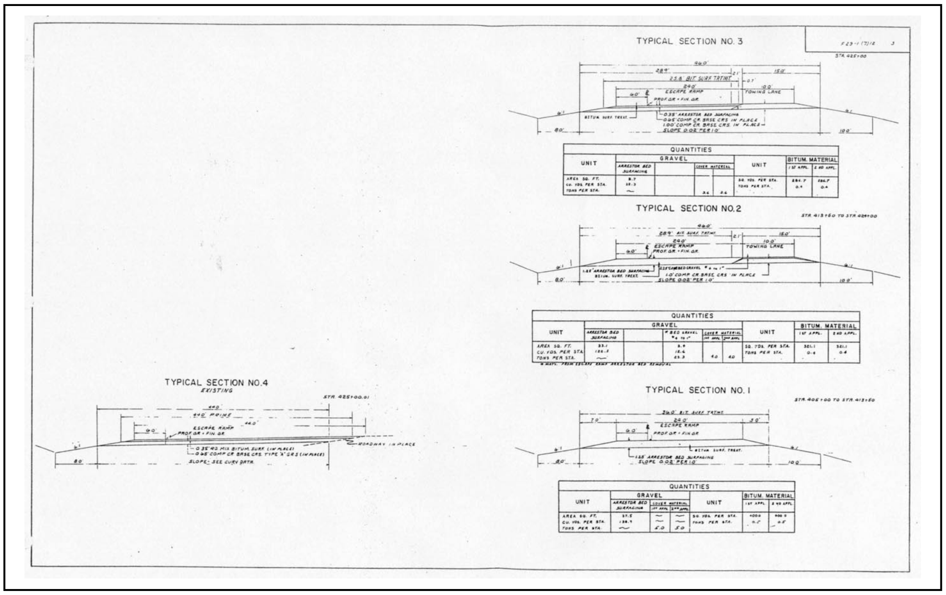


Figure 3.2.20
Montana Route 287 Truck Escape Ramp Plan and Profile (MDT)

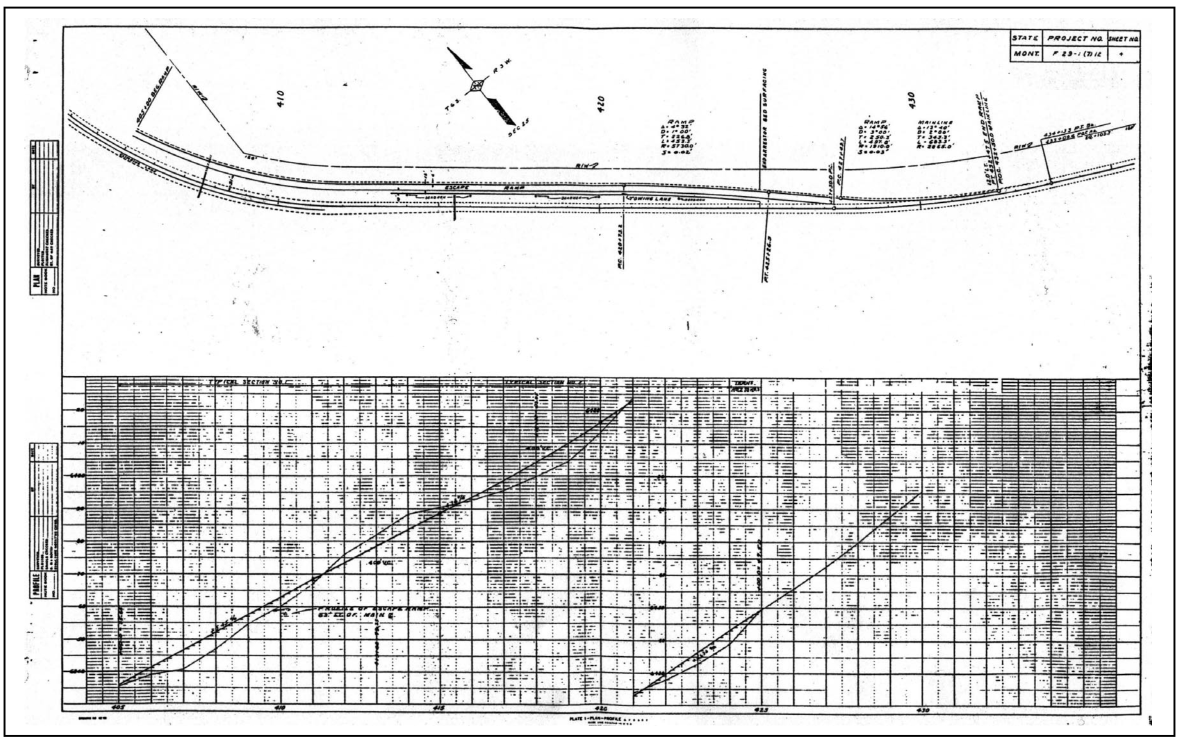


Figure 3.2.21
Interstate Route 90 Truck Escape Ramp Typical Section (MDT)

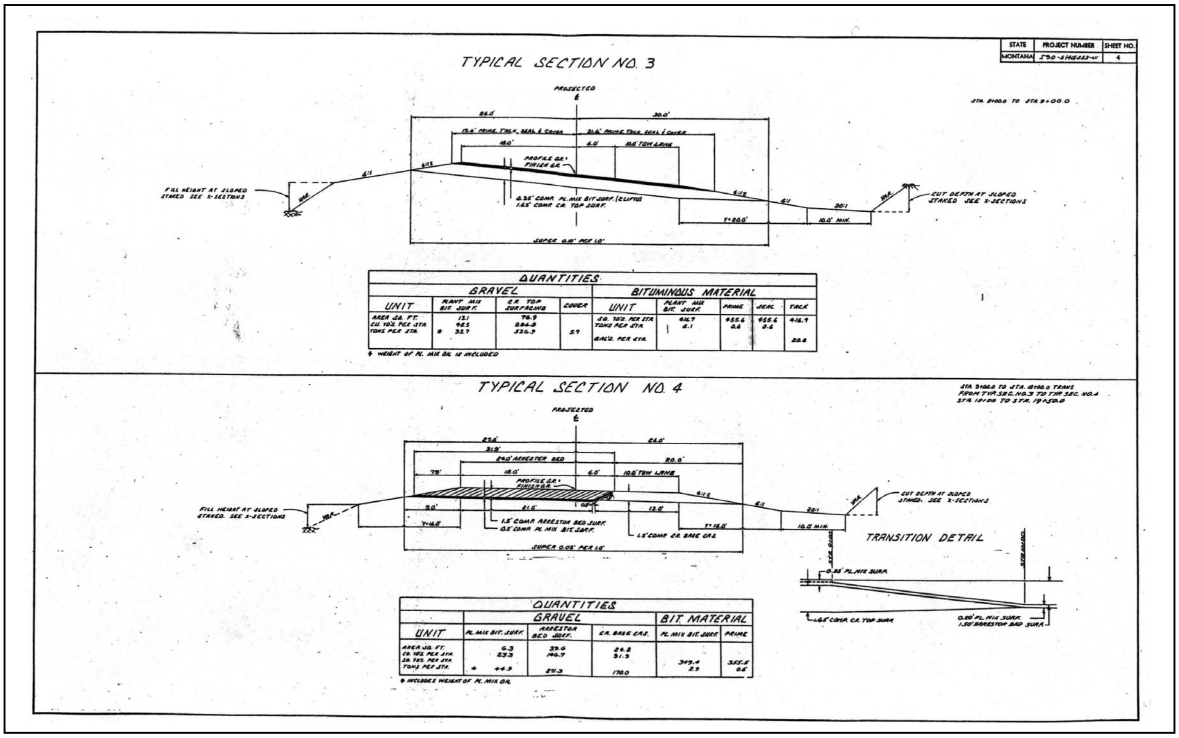


Figure 3.2.22
Interstate Route 90 Truck Escape Ram Plan and Profile 1 (MDT)

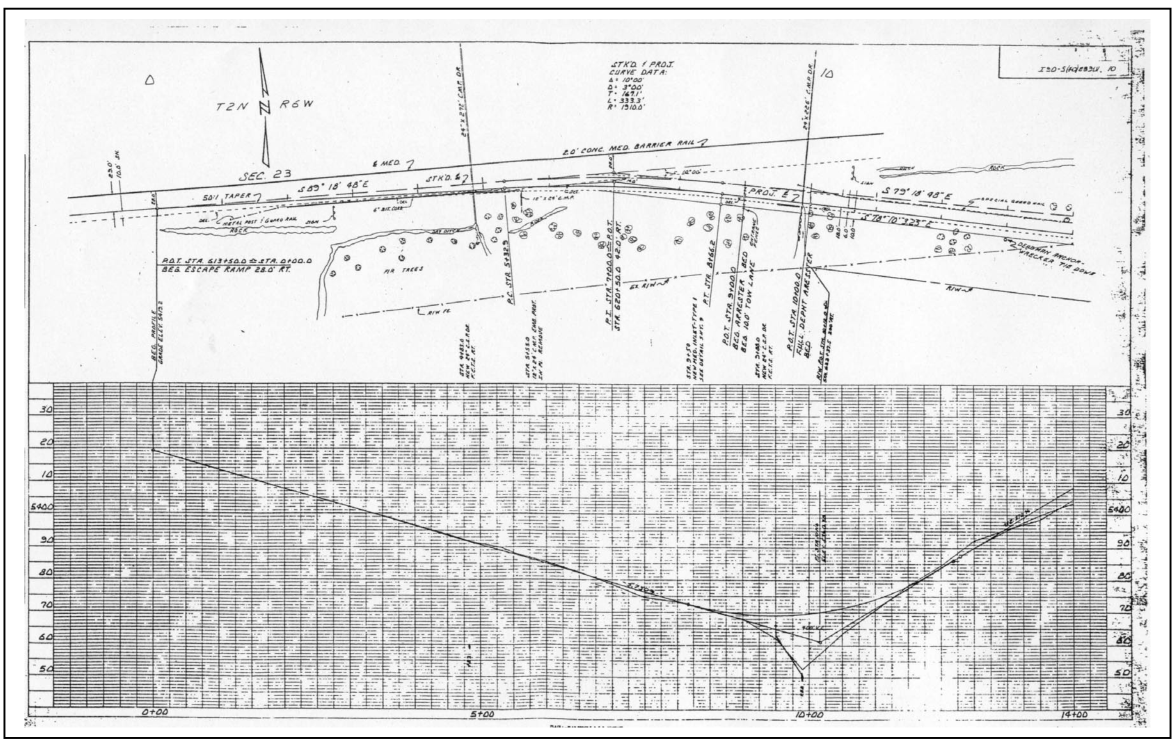
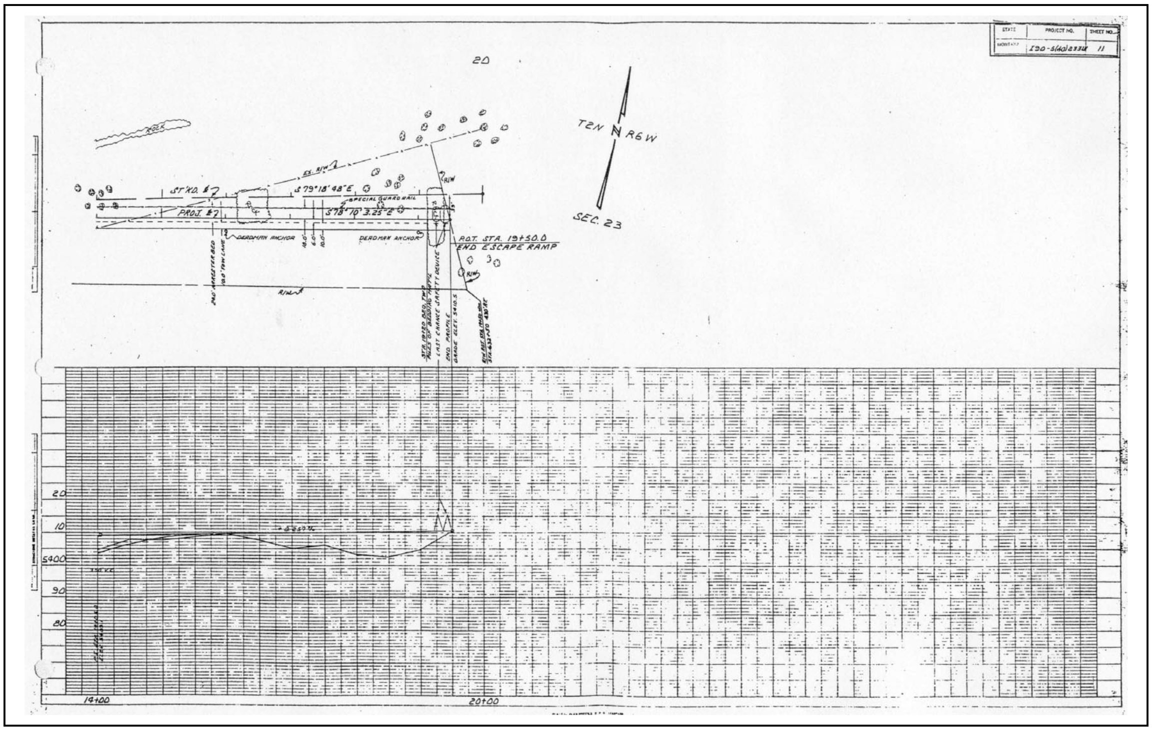


Figure 3.2.23
Interstate Route 90 Truck Escape Ramp Plan and Profile 2 (MDT)



Nevada Department of Transportation (NDOT)

NDOT does not have specific guidelines for the installation of truck escape ramps (TERs), although there are a number of them located throughout the State. Contact with the DOT established past experience along with the NCHRP Synthesis of Highway Practice 178 – Truck Escape Ramps and the AASHTO A Policy of Geometric Design of Highways and Streets as the key factors in determining need, location and design.

NDOT currently has three TERs, all of which are of the gravel arrester bed design. Cost of construction and terrain are sited as the two critical considerations. Experience has found that trucks rarely travel more than 500 feet into the ramp. NDOT does not mandate that brake check areas be provided at the summit, but where they exist, these areas contain information on the percent grade, length of grade and location of the TER along the downgrade. NDOT does provide signage 1 mile and ½ mile in advance of the TER. The gravel used must be clean, same size and have proper resistance to stop the out-of-control vehicle. The State of Nevada does fine vehicles for using the ramps, but indicates that it likely does deter usage.

The most recent TER constructed in Nevada is along SR 163 near the City of Laughlin. The TER is a descending grade arrester bed (See **Figure 3.2.24**). The total ramp length is 2061 feet, with the arrester bed making up 700 feet of the total. The TER has a "last chance" mound constructed on the final 36 feet, with specifications indicating that the height is not to exceed 9.8 feet (See **Figure 3.2.25**). The grade of the TER varies from –3.409% at entry to a final slope of –2.986% (See **Figure 3.2.26**).

Figure 3.2.24
State Route 163 Truck Escape Ramp Typical Section (NDOT)

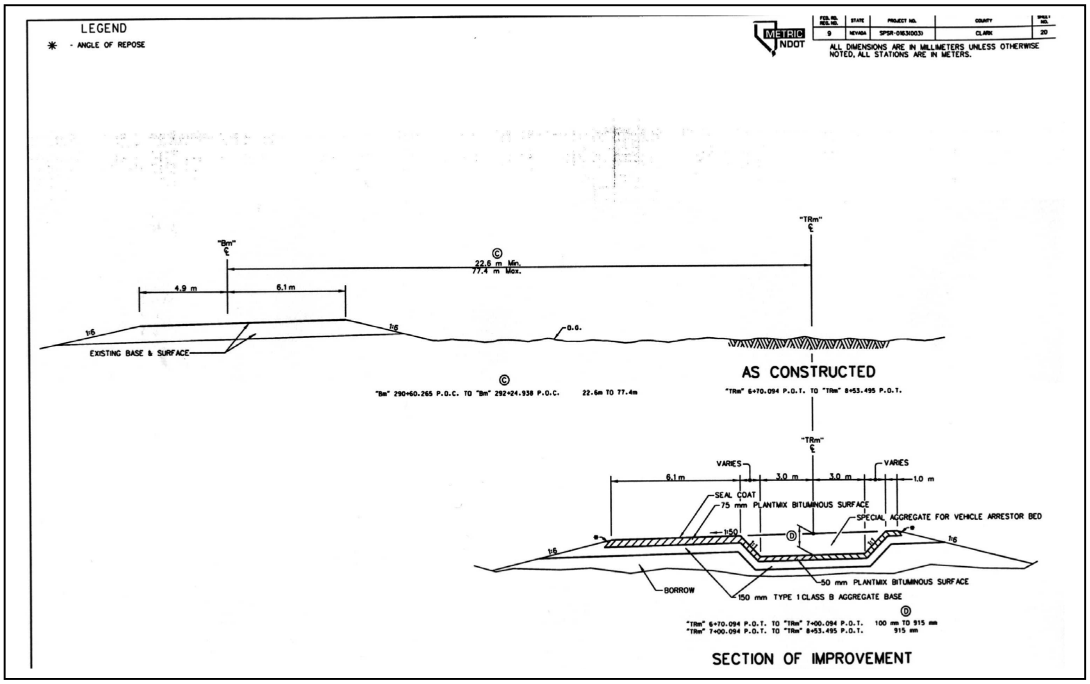


Figure 3.2.25
State Route 163 Truck Escape Ramp Plan (NDOT)

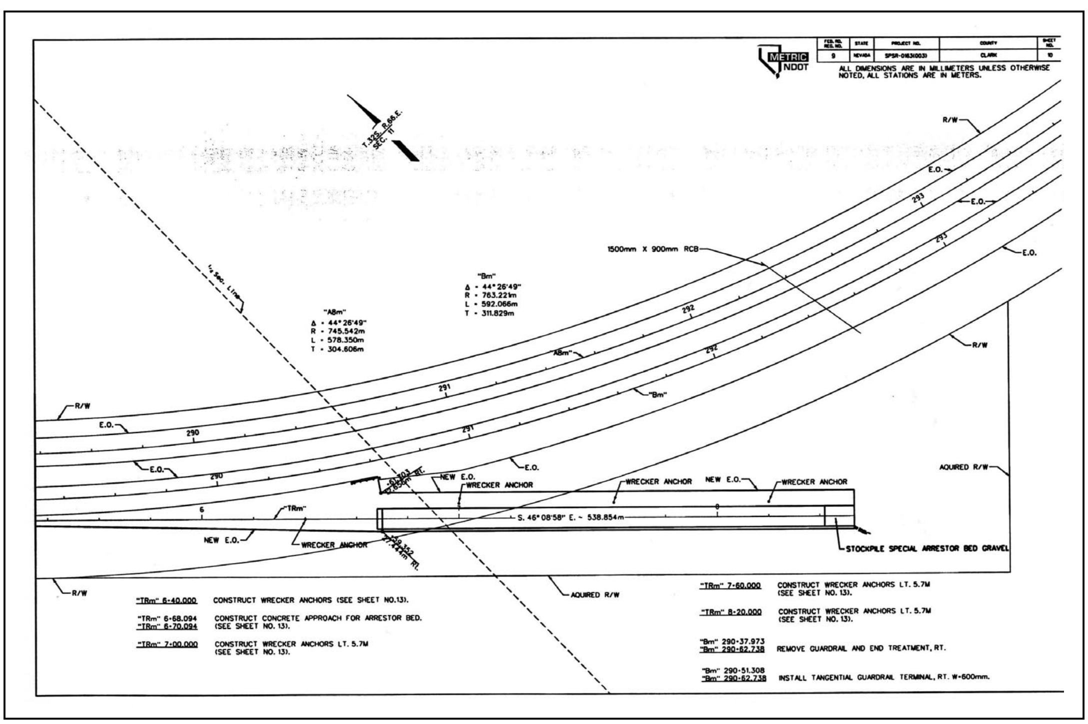
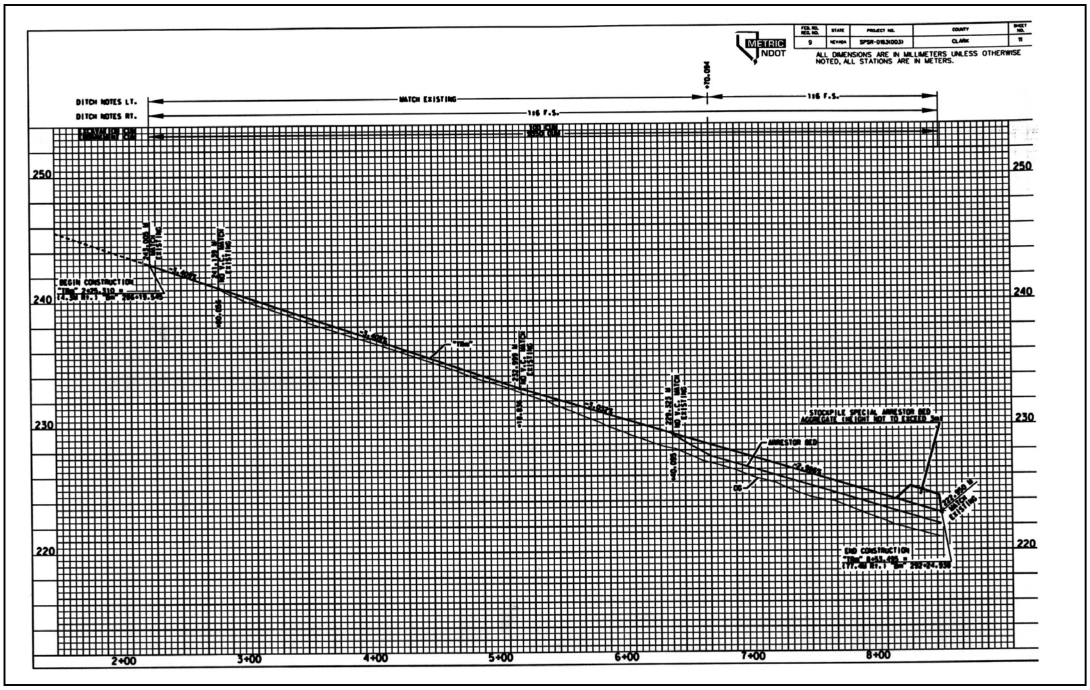


Figure 3.2.26
State Route 163 Truck Escape Ramp Profile (NDOT)



The TER exits to the right of the mainline, with a 20-foot service road between the TER and the roadway. Wrecker anchors are provided along the service road side spaced every 200 feet. The aggregate varies from 4 inches at the point of entry to a maximum depth of 36 inches in the first 100 feet. The bed maintains the depth of 36 inches for the remainder of its length. The arrester bed is lined with a plantmix bituminous surface, similar to the service road.

North Carolina Department of Transportation (NCDOT)

The NCDOT Roadway Design Manual recommends not only constructing TERs on long mountain grades in rural areas, but also in urban areas on steep, short grades where high truck volumes are mixed with dense traffic and development, as urban areas have a higher probability of fatalities and property damage.

Additionally, they recommend an area at the top of the grade for truckers to check their brakes, read information about the upcoming grade and TER, and shift to the correct gears for the downgrade.

While NCDOT recognizes that specific warrants and processes for the justification of TERs have not been formalized, it states the principal factor for a TER need is determined by runaway accident experience. Conditions such as grade, length of grade, horizontal alignment and end-of-grade conditions all weigh equally. Average daily traffic (ADT) and percent trucks also weight about as much as the conditions above. While available right of way and topography are factors in site selection, they are not factors in determining the need for a TER.

NCDOT references the "Grade Severity Rating System (GSRS)" as a mechanism for determining the need and location of TERS, as well as the NCHRP *Synthesis of Highway Practice 178 – Truck Escape Ramps* and AASHTO A Policy on Geometric Design of Highways and Streets for additional information.

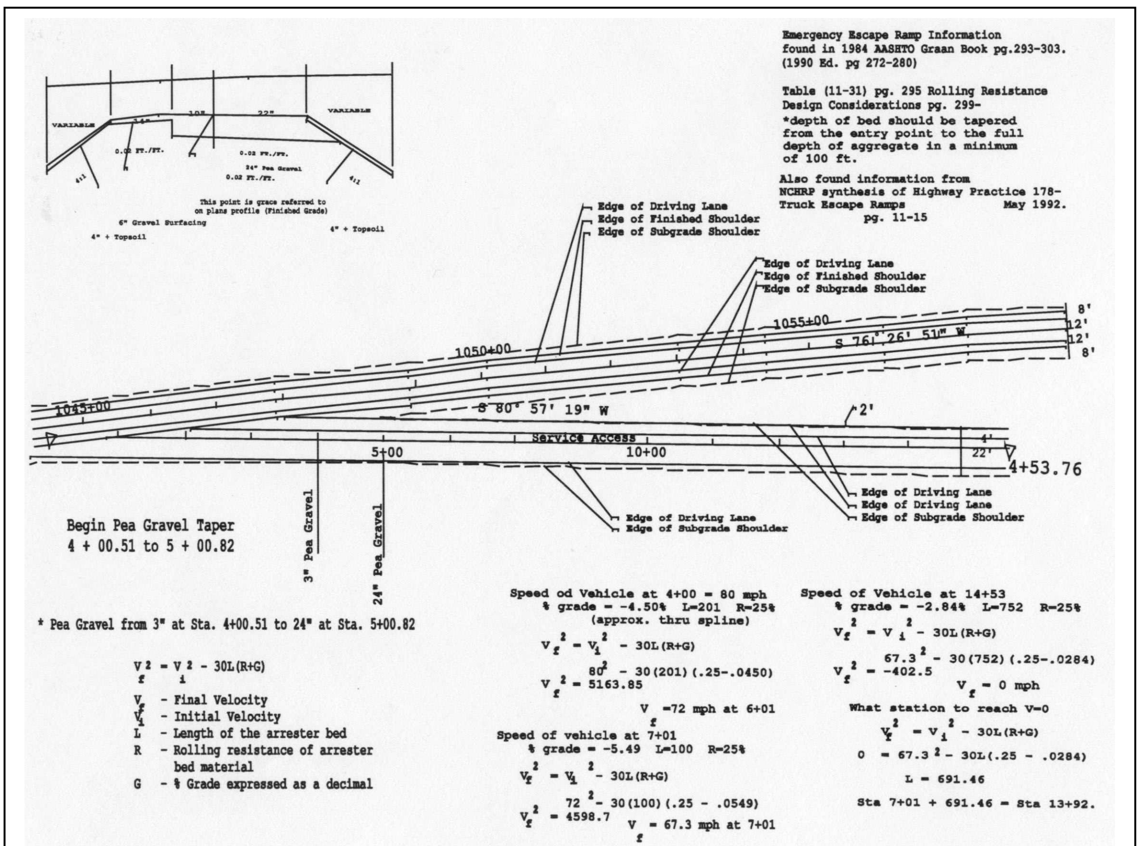
South Dakota Department of Transportation (SDDOT)

The SDDOT *Roadway Design Manual* recommends the design and construction of a TER where long descending grades exist or where topographical and location controls require such grades on new alignments. It goes on to state that out-of-control vehicles are typically the result of an operator losing control of the vehicle because of loss of brakes either through overheating or mechanical failure, or failure to down shift at the appropriate time.

While specific guidelines for the design of TERs is lacking, the principal influence used by SDDOT in warranting a TER is a history of runaway truck accidents. Other factors considered are site conditions such as length of grade, percent of grade, and a combination of horizontal alignment and end-of-grade conditions.

SDDOT references the NCHRP *Synthesis of Highway Practice 178 – Truck Escape Ramps* for detailed alternatives as well as the AASHTO A Policy on Geometric Design of Highways and Streets for design considerations. An example of a SDDOT detailed analysis is included below (See **Figure 3.2.27**).

Figure 3.2.27
Escape Ramp Layout (SDDOT Figure 6-19)



Utah Department of Transportation (UDOT)

The UDOT procedures manual does not have a policy on truck escape ramps (TERs), although TERs do exist within the state. Similarly, there are no design standards for TERs. UDOT refers to the AASHTO A Policy on Geometric Design of Highways and Streets for need, location and design details.

Washington State Department of Transportation (WSDOT)

The WSDOT Design Manual (November 1999) recommends the consideration of an emergency escape ramp whenever long steep downgrades exist. It recommends consultation with local maintenance personnel and verification of accident records to determine if an escape ramp is justified.

WSDOT recognizes the following types of TERs:

- Gravity escape ramps, which are ascending ramps paralleling the traveled way. Their long length and steep grades can present drivers with control problems, and are the least desirable design.
- Sandpile escape ramps, which are piles of loose, dry sand dumped at the ramp site, are usually not more than 400 feet long. Their deceleration is usually high and the sand can be affected by weather. They are more desirable than gravity escape ramps, but less desirable than arrester beds.
- Arrester bed escape ramps, which are parallel ramps filled with smooth, coarse, free-draining gravel. They stop vehicles by increasing the rolling resistance, and are commonly built on an upgrade to add the benefits of gravity to the rolling resistance.

WSDOT states that the location of a TER will vary depending on terrain, length of grade, and roadway geometrics. The best locations include in advance of a critical curve, near the bottom of the grade, or before a stop. It is desirable that the ramp departs the roadway on a tangent at least 3 miles from the beginning of the downgrade.

The length of the ramp will vary depending on which type is selected, with a minimum length of 200 feet. WSDOT uses the same equation and values as presented above in the AASHTO section. Similarly they note that speeds of out-of-control vehicles rarely exceed 90 mph. It is desirable for the ramp to be wide enough to accommodate more than one vehicle. A minimum width of 26 feet should be used, with a desirable width of 40 feet.

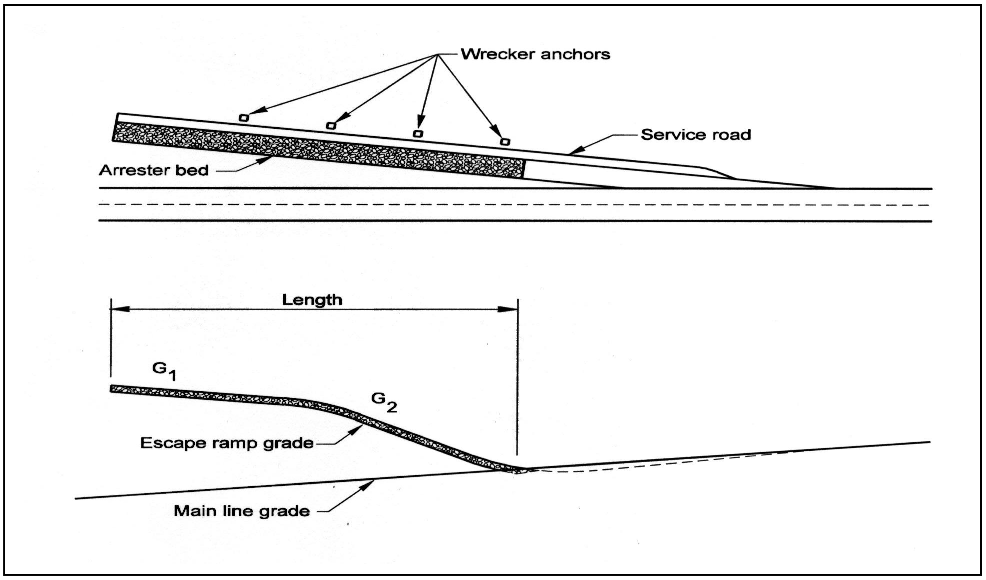
WSDOT provides the following items for consideration in the design of TERS:

- If possible, at or near the summit, provide a pull-off brake check area. Include information about the upcoming grade, geometry and TER.
- A free draining, smooth, noncrushed gravel is preferred for an arrester bed. Taper the depth of the bed from 3 inches at the entry to a full depth of 2 to 2 ½ feet in not less than 100 feet.
- Mark and sign in advance of the ramp using MUTCD standard signage.
- Consider providing an impact attenuator at the end of the ramp is space is limited.

- Provide a surfaced service road adjacent to the arrester bed for wrecker and maintenance vehicles to remove vehicles and make repairs to the arrester bed. Provide anchors at 300-foot intervals to secure the wrecker during removal.

A typical TER is provided below (See **Figure 3.2.28**).

Figure 3.2.28
Typical Emergency Escape Ramp Plan and Profile (WSDOT Figure 1010-8)



Summary
After a review of adjacent DOT policies and design standards on the location, need and design of TERs, it became increasingly evident that there still exists no clear-cut methodology for the determination of need and location of TERs. Many States do not have their own standards, but refer to the NCHRP *Synthesis of Highway Practice 178 – Truck Escape Ramps* and the AASHTO A Policy on Geometric Design of Highways and Streets as guidelines to be used. States that do have their own standards such as California and Washington State do not agree on every aspect of TER design. The table below (See **Table 3.2.3**) presents a review of information found organized by state.

It is obvious from looking at the table below that a majority of the information used in the design of TERs comes from the NCHRP *Synthesis of Highway Practice 178 – Truck Escape Ramps* and the AASHTO A Policy on Geometric Design of Highway and Streets. While these two pieces of literature do not agree on every aspect of TER design, they do for the most part mimic one another in minimums to be used.

Table 3.2.3
State Agency Comparison of Published Criteria

<table>
<tr><th>Agency</th><th>Indication of Need</th><th>Determination of Location</th><th>TER Types</th><th>Preferred TER Type</th><th>Width of Preferred</th><th>Length of Preferred</th><th>Arrester Bed Material</th><th>Material Depth</th><th>Miscellaneous</th></tr>
<tr><td>Caltrans</td><td>Number of incidents involving runaway vehicle.</td><td>Dependant on terrain. Only on lower half of grade, along tangent section.</td><td>1. Gravity
2. Arrestor Bed</td><td>Arrestor Bed</td><td>26 foot (min)</td><td>AASHTO Green Book</td><td>Sand to 1 ½ inch aggregate. Prefer</td><td>36 inches preferred, 30 inches absolute minimum, tapered</td><td>12 – 14 foot service road Anchors spaced 150 feet</td></tr>
<tr><td>CDOT</td><td colspan="9">No information contained in design manual, as-built plans included.</td></tr>
<tr><td>MDT</td><td colspan="9">No information contained in design manual, as-built plans included.</td></tr>
<tr><td>NDOT</td><td colspan="9">References NCHRP Synthesis of Highway Practice 178 – Truck Escape Ramps and AASHTO A Policy on Geometric Design of Highways and Streets.</td></tr>
<tr><td>NCDOT</td><td colspan="9">References “Grade Severity Rating System (GSRS)”, NCHRP Synthesis of Highway Practice 178 – Truck Escape Ramps and AASHTO A Policy on Geometric Design of Highways and Streets.</td></tr>
<tr><td>SDDOT</td><td>History of runaway truck accidents</td><td colspan="8">References NCHRP Synthesis of Highway Practice 178 – Truck Escape Ramps and AASHTO A Policy on Geometric Design of Highways and Streets.</td></tr>
<tr><td>UDOT</td><td colspan="9">References the AASHTO A Policy on Geometric Design of Highways and Streets.</td></tr>
<tr><td>WSDOT</td><td>Long steep downgrades with history of high accidents.</td><td>Terrain, length of grade, and roadway geometrics.</td><td>1. Gravity
2. Sandpile
3. Arrester Bed</td><td>Arrester Bed</td><td>26 foot (min), 40 foot (preferred)</td><td>AASHTO Green Book</td><td>Free draining, smooth, noncrushed gravel</td><td>3 inches to 30 inches, tapered</td><td>Brake check area, impact attenuator, surfaced service road and anchors every 300 feet.</td></tr>
</table>

3.2.5 Professional Society and Organization Publications

American Society of Civil Engineers

The *Journal of Transportation Engineering* (September/October 1997) published by the American Society of Civil Engineers (ASCE) features an article entitled "Determining Need for and Location of Truck Escape Ramps". Cited in other publications, this work is considered by many to be the current state of practice with respect to need and location.

The article does state early on that truck escape ramps (TERs) are not the only solution to the out-of-control vehicle problem. Additional countermeasures such as reducing the maximum gross vehicle weight (GVW), reducing the posted speed limit and providing pullout areas at summits should be considered when addressing this problem. The article goes on to cite portions of the NCHRP *Synthesis of Highway Practice 178 – Truck Escape Ramps,* which is described in detail below.

The article first poses a discussion on the need for TERs, followed by a discussion on the location of them. It notes that it is often the combination of grade and curvature, not the severity of grade, which causes a vehicle to lose control. The author cites the "Grade Severity Rating System (GSRS)" as the most widely used tool to assess the need for TERs, but cautions about this being the sole factor. The GSRS determines the maximum safe speed based on vehicle weight and brake temperatures. The maximum safe speed is defined as "that speed from which an emergency stop at the bottom of the grade will not generate brake temperatures above a pre-selected temperature limit."

To begin analysis for the determination of need, the following assumptions must be made:

1. What type of vehicle, gross vehicle weight and brakes will the design vehicle have?
2. Is the approach roadway equipped with a brake check area, and does that area provide information relative to the downgrade ahead?
3. Will the driver stop at the brake check area, will they check their brakes and will they select the proper gear for the downgrade?

The following factors were considered by the authors to be the primary considerations in the determination of need:

- Grade severity, including length and steepness of grade
- Cornering limitations, cornering speeds of horizontal alignment
- Accident history, frequency of previous runaway accidents, and
- Accident consequences, conditions at bottom of grade.

The authors then go one step further to identify the following steps in determining the need for a TER on a specific downgrade:

1. Select the design vehicle, including GVW and brake-fade temperature (temperature at which brakes begin to loss efficiency).
2. Check for the presence of a brake-check area at the top of grade.
3. Identify the following two scenarios regarding the action taken by the truck driver:
    a. The driver will stop at the brake-check are (if one is provided), and will thus begin the descent from a complete stop.

   b. The driver will not stop at the brake-check area and will thus begin the descent at the posted speed limit.
4. Prepare the following plots for comparison using the same horizontal scale
   a. Downgrade profile
   b. Truck speed profile, indicating limiting speed of all curves
   c. Track brake temperature profile
   d. Accident locations along the downgrade
5. Identify locations where:
   a. Estimated downgrade truck speed exceeds the limiting speed
   b. Brake temperature exceeds the "fade temperature"

If after completion of these steps and at least one location is found that satisfies the conditions of Step 5, the need for a TER has been established. This need can further be analyzed considering the following factors:

- Presence of previous runaway truck accidents.
- Presence of fixed objects, especially houses, schools and intersections within the path of a runaway vehicle near a limiting curve or at the bottom of grade.

To complete the process above, the downgrade speed, curve cornering speed and brake temperature all need to be calculated. The speed profile can be estimated using the following equation:

$$V_x = \sqrt{(V_i^2 - 2gh_x)}$$

where: V_x = speed at a distance x from the top of grade (ft/s)
V_i = initial speed at top of grade (ft/s)
g = acceleration due to gravity (32.2 ft/s^2)
h_x = difference in elevation at distance x (negative) in feet.

The curve cornering speed is defined as the maximum speed at which a vehicle can negotiate a curve without overturning due to centrifugal acceleration, and is calculated in its simplest form by:

$$V_c = 3.6 \sqrt{(\alpha g R)}$$

Where: V_c = cornering speed in miles per hour
α = maximum lateral acceleration rate multiplier (0.30 – 0.40 for trucks)
g = acceleration due to gravity (32.2 ft/s^2)
R = radius of the curve in feet.

The most common technique used to generate a heat profile is the GSRS.

Once a need has been established, the proper location must now be determined. From the equations and methodology explained above, the following eight combinations are possible (See **Table 3.2.4**).

Table 3.2.4
Determination of Need and Location Scenarios

Case	Condition	TER Needed?	Priority
1	Descent speed does NOT exceed cornering speed. Brake temperature does NOT exceed fade temperature. Stationary objects do NOT exist within path of runaway vehicle.	No	--
2	Descent speed DOES exceed cornering speed. Brake temperature does NOT exceed fade temperature. Stationary objects do NOT exist within path of runaway vehicle.	No	--
3	Descent speed does NOT exceed cornering speed. Brake temperature DOES exceed fade temperature. Stationary objects do NOT exist within path of runaway vehicle.	No	--
4	Descent speed does NOT exceed cornering speed. Brake temperature does NOT exceed fade temperature. Stationary objects DO exist within path of runaway vehicle.	No	--
5	Descent speed DOES exceed cornering speed. Brake temperature does NOT exceed fade temperature. Stationary objects DO exist within path of runaway vehicle.	Yes	Low
6	Descent speed DOES exceed cornering speed. Brake temperature DOES exceed fade temperature. Stationary objects do NOT exist within path of runaway vehicle.	Yes	Moderate
7	Descent speed does NOT exceed cornering speed. Brake temperature DOES exceed fade temperature. Stationary objects DO exist within path of runaway vehicle.	Yes	Moderate
8	Descent speed DOES exceed cornering speed. Brake temperature DOES exceed fade temperature. Stationary objects DO exist within path of runaway vehicle.	Yes	High

Cases 5 through 8 indicate that a TER is warranted at this location, with Case 8 having the highest priority. It should be noted that some researchers disagree with the determination of need being “No” for Case 4, in which stationary objects (houses, schools, intersections, etc.) do exist within the trajectory of the out-of-control vehicle.

Transportation Research Board

The Transportation Research Board (TRB) is a unit of the National Research Council, a private, nonprofit institution that is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. TRB’s main method for distributing this research information is the *Transportation Research Record* (*TRR*).

Two *TRR*s were located that contained information relative to truck escape ramps (TERs), *TRR 736* and *TRR 923*. The first (*TRR 736, 1979)*) contains two articles while the second (*TRR 923, 1983*) contains one.

The article “State Practice and Experience in the Use and Location of Truck Escape Facilities” (*TRR 736*) provides a 1979 overview of what various state DOTs were considering with respect to the need and location of TERs.

The article notes that a large percentage of runaway vehicle accidents result in fatalities, identifying a need to improve public safety. It also notes that while the state-of-the-art for escape ramp construction has increased over time, the same cannot be said for escape ramp warrants. Specifically, there are no widely excepted guidelines for the development of TERs.

Five considerations are listed that should be accounted for in the design and construction of TERs:

1. The ramp length is dependant on the aggregate used.
2. The ramp should be wide enough to accommodate more than one vehicle.
3. Only clean, free draining aggregate should be used in the arrester bed.
4. A surfaced road adjacent to the arrester bed is necessary for vehicle removal and maintenance.
5. Anchors should be installed adjacent to the arrester bed for tow trucks.

The article polled 23 state highway agencies to establish a ranking of criteria used to warrant need and location. The results are listed below.

Factors considered by State highway agencies in determining the need for TERs, followed by percent of agencies using factor:

1. Runaway truck accident rates, 61%
2. Length of grade, 35%
3. Percent grade, 35%
4. Percent trucks, 22%
5. Conditions at bottom of grade, 17%
6. Average daily traffic (ADT), 13%
7. Horizontal curvature, 13%
8. Accident severity, 4%

9. Available right-of-way, 4%
10. Topography, 4%

Factors considered by state highway agencies in determining the location of TERs, followed by percent of agencies using factor:

1. Topography (earthwork costs), 35%
2. Horizontal alignment, 22%
3. Accident location, 22%
4. Condition at bottom of grade, 9%
5. Available right-of-way, 4%
6. Truck driver input, 4%
7. Speeds of out-of-control vehicles, 4%
8. Length of grade, 4%

The article concluded by stating that escape ramps have proven effective as an accident countermeasure and they are becoming more and more common along steep downgrades. It did note that while few States follow specific criteria for the determination of need and location, accident experience along with length of grade and percent grade were the most common factors to determine need, and topography, horizontal alignment and accident location were the most common factors to determine location.

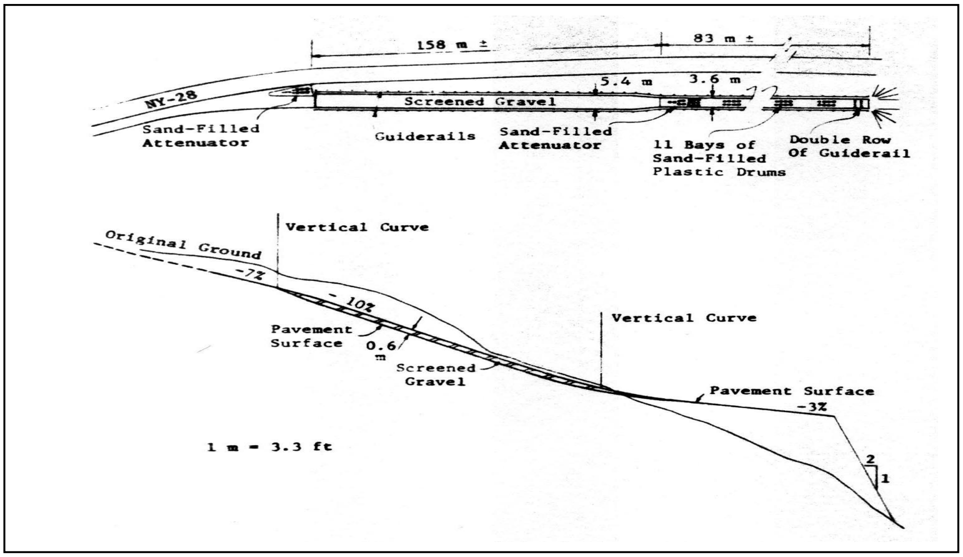
The article "Performance of a Gravel-Bed Truck-Arrester System" (*TRR 736*) provides a review of a TER installed along NY-28 near the Village of Mohawk, New York. The article provides a look at a hybrid ramp, using a gravel arrester bed upon entry, and transitioning to sand barrels approximately 500 feet past entry (See **Figure 3.2.29**).

The ramp design was basically separated into two sections, the gravel arrester bed and the sand filled drum section. The arrester bed was designed to a length of 528 feet. The bed was 18 feet wide at the point of entry, tapering to 12 feet wide near the end. The bedding material consists of screened, rounded pea gravel, with a depth increasing from 0 feet at entry to a maximum depth of 2 feet in the first 50 feet. The depth tapers back to 0 feet prior to the sand drums. The arrester bed is lined with the approach pavement.

The second section consists of a total of 88 sand-filled plastic drums arranged in 11 bays over a distance of approximately 275 feet. The drums are supported on corrugated metal pipe pedestals to match their center of mass with that of large trucks. The drums are followed by two rows of heavy post-corrugated beam guardrail, to stop any vehicle that advances through the arrester bed and drums.

Guardrail was installed along both edges of the arrester bed and drum section to protect against jack-knifing and to ensure the out-of-control vehicle strikes the drums head-on. The ramp is signed in advance, to provide out-of-control vehicle drivers the opportunity to prepare for the ramp, and to inform other motorists of the potential for runaway accidents. The ramp is not bordered by a service road, and there is no evidence of anchors. A mandatory truck pullout is positioned prior to the descent to provide a brake check location and allow for the transition to lower gears.

Figure 3.2.29
State Route 28 Truck Escape Ramp Plan and Profile (NYDOT)



Three tests were run on the TER using a 37,000-pound (loaded) two-axle dump truck at speeds of 21, 41, and 56 mph. The tests concluded that the arrested bed safely stopped the truck prior to the sand drums. The driver indicated that at 56 mph, the vehicle was controllable, but that some pitching motion and yaw developed. The truck traveled a distance of 300 feet into the arrester bed at 56 mph and made no contact with the side guardrails. The following conclusions were drawn from the tests:

- The average decelerations experienced were no greater than would be experienced in a panic stop on dry pavement.
- Narrowing the chute width may be helpful in preventing excessive yaw and jack-knifing at high speeds.
- A suitably located tow anchor is probably necessary to remove heavy vehicles from the arrester bed.
- Post-impact maintenance requirements for the gravel bed were minimal.

The article "Current State of Truck Escape-Ramp Technology" (*TRR 923*) provides a review of design considerations and aspects of truck escape ramp technology found throughout the United States prior to 1983. The author states that the primary reason for the use of truck escape ramps is to reduce the runaway truck hazard on long, steep downgrades where drivers have lost control of their vehicles, typically due to loss of brakes.

The article identifies six different types of escape ramps; sandpile, gravity, ascending grade arrester bed, horizontal grade arrester bed, descending grade arrester bed and roadside arrester bed. These six alternatives utilize two basic methods of deceleration: vehicles decelerating due to the effects of gravity and vehicles decelerating due to an increase in rolling resistance provided by an arresting material.

In determining which ramp type will provide the greatest benefit at a specific location, several characteristics associated with ramp type need to be taken into consideration. The first consideration is the length of the ramp. The required length of a ramp depends upon the design entry speed, type of arresting material and percent grade. Since different ramps utilize different arresting materials, the lengths of the various ramps will differ.

Sandpile ramps are usually the shortest of the TERs, with lengths usually less than 400 feet. Gravity ramps are typically long because they only use one method of deceleration: gravity. Their lengths can reach up to 1,500 feet or more. The various types of arrester bed ramps vary in length depending on the material used (rolling resistance) and the extent to which gravity assists in deceleration. Their lengths usually vary between 300 to 1,800 feet.

The article explains that TER width is not generally a function of ramp type; rather it is related to the presence of backup measures used when the TER is already in use. This could consist of an additional ramp further downgrade or a ramp of sufficient width to accommodate two runaway vehicles. It states that arrester beds and sandpiles typically need to be wider than gravity ramps, which are typically between 12 and 14 feet wide, as they contain a runaway vehicle for a longer period of time. For these reasons, sandpiles and arrester beds are typically wide enough to accommodate two vehicles (less cost than constructing two separate TERs). Arrester beds are typically between 26 and 30 feet wide, although some are as wide as 50 feet and as narrow as 16 feet. The width of an arrester bed or sandpile typically tapers towards the end to channelize the vehicle and reduce excessive yaw and the possibility of jack-knifing.

The material used in an arrester bed is independent of the grade, but will contribute to the length of the arrester bed as various materials have difference rolling resistance forces. Pea gravel and loose gravel are the two most common aggregates used, but the type used at any particular location is a function of availability and cost. Pea gravel is the most desirable because of its high percentage of voids, which allows the bed to drain quickly.

The author notes that experience has proven that while sandpile TERs function better with surface ridges (irregular mounds on the surface), arrester bed TERs function better if the arresting material is smooth.

At the time this report was published (1983) the cost between the cheapest TERs and the most expensive ranged from $10,000 to over $500,000. Primary costs to construct a TER must include excavation, right-of-way, and local labor costs, along with materials. To this end, sandpile TERs are historically the cheapest ranging from $10,000 to $25,000 (1975 dollars), while arrester beds are the most expensive. A recent TER constructed in Nevada cost over $1M.

Secondary costs associated with maintenance of the TER must also be included in the determination of what type of ramp to construct. Gravity ramps are the closest to being maintenance free; although rollback induced jack-knifing requires some maintenance. Sandpile and arrester bed ramps require maintenance after every use. Aggregate in arrester beds must also be changed periodically when too many fines have collected to allow for proper drainage.

The article states that most TERs in United States exit to the right side of the mainline traffic.

A dual signing approach is recommended to provide information of the grade ahead, pullout area and presence of a TER along with signage guiding the out-of-control vehicle into the ramp. The author recommends use of MUTCD standard signs to simplify TER design and provide some consistency between States. Additionally, the ramp will need to be properly delineated so the ramp is obvious to an out-of-control vehicle operator, but mainline traffic does not confuse it for a through movement. To remedy this confusion, the author follows previous recommendations to use red delineators for TER exit areas as oppose to yellow or white, which are used along highway mainlines.

The possibility of two out-of-control vehicles proceeding on a downgrade at roughly the same time must be taken into consideration, and backup measures considered. This is typically, as stated above, accommodated with the presence of an additional ramp downgrade or a wider TER width. Since gravity ramps do not "trap" the runaway vehicle, the likelihood of the TER being occupied is less. Arrester beds and sandpiles will "trap" a vehicle, sometimes for several hours, and therefore their width is increased to 26 feet or more to allow for the safe entrance of two vehicles. Regardless of the backup measure, TERs should always be designed so the driver of the vehicle can see the entire ramp, occupied or not.

In 1992, the Transportation Research Board, in cooperation with the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA) and the National Cooperative Highway Research Program (NCHRP) published NCHRP Synthesis 178 - Truck Escape Ramps: A Synthesis of Highway Practice. The report provides an overview of truck escape ramp (TER) theory and practice to date, followed by discussions on the location of TERs, TER design, operational considerations and maintenance.

By definition, NCHRP Synthesis 178 presents a review of previously published theory and practice. It has influenced a majority of Federal and state agencies over the past decade, and its content can be visible in almost every report written since its publication. Thus it repeats a majority of the points highlighted in the research included above. To that end, only the conclusions that are reached at the end of the synthesis are included below.

Synthesis 178 found that the preferred design for TERs is the arrester bed. The arresting aggregate should be rounded gravel no less than 36 inches in depth. Uniform grading with an approximate size of 0.5 to 0.7 inches provides the greatest rolling resistance, producing shorter length ramps.

TERs should be as straight as possible, at a minimum departure angle from the mainline roadway. Provisions to avoid contamination of the aggregate are essential, and maintenance must include regrading after each use and periodic fluffing of the aggregate.

Last chance devices such as aggregate mounds or barrels should be used only when the needed ramp length cannot be provided. When used, vehicles should be traveling no more than 25 mph at impact. Removal of runaway vehicles must be facilitated by a service road and wrecker anchors. Proper signage along the downgrade and at the TER itself should be in place to ensure the ramp is used properly.

Summary
The societies presented above, while consistent with one another on some aspects, do not wholly agree on the determination of need, location and design of truck escape ramps (TERs). One contends that it is not the severity of grade that causes a vehicle to lose control, but rather the combination of grade and curvature, while the other contends that it is the length and grade that contribute to the loss of control. The authors do agree that brake failure, typically caused by overheating, is the most common reason

One society notes that TERs are not the only solution to the runaway vehicle problem; countermeasures such as reducing GVW and posted speed limits along with providing brake check pullouts at the summit may also assist in the problem.

In total, six different types of TERs are identified: sandpile, gravity, ascending grade arrester bed, horizontal grade arrester bed, descending grade arrester bed, and roadside arrester bed. The ramps rely on two basic methods of deceleration, namely gravity and rolling resistance.

There are two separate guides for determining need presented. One presents a list of criteria examined on the generic level, while the other goes more in-depth. The in-depth method requires, in some cases, extensive calculations within the following steps:

1. Select a design vehicle.
2. Is there a brake check area?
3. Will the driver use it?
4. Prepare downgrade, speed, and brake temperature profiles. Locate high accident locations.
5. Identify locations where profiles overlap.

The other method proposed relies more on statistics rather than calculations. The following characteristics are considered by most DOTs:

- Runaway truck accident experience
- Length of grade
- Percent grade
- Percent trucks, and
- Conditions at bottom of grade.

In the first method, the locations in Step 5 indicate where a TER would be most effective. In the second method, the following characteristics are used to determine the best location:

- Topography (earthwork costs)
- Horizontal alignment
- Accident locations, and
- Conditions at bottom of grade.

The ramp length is dependent on the aggregate used. The ramp should be wide enough to safely accommodate more than one vehicle. When arrester beds are used, only clean, free draining aggregate should be used. A surface road should be provided adjacent to the TER, with anchors installed for use by wreckers in the case of arrester beds. Signage along the roadway and in the vicinity of the TER should be in accordance with the MUTCD.

A case study was conducted on a TER is New York that consisted of an arrester bed of approximately 530 feet followed by a second section consisting of 88 sand-filled plastic drums, approximately 280 feet long. The ramp was constructed with an initial width of 18 feet, tapering down to 12 feet prior to the second section. The bedding material was pea gravel, with a tapered depth of zero at entrance to a maximum depth of 2 feet within the first 50 feet. A mandatory truck pullout is positioned at the top of the summit, but there is no service road or anchors positioned adjacent to the TER. The arrester bed is lined with the approach pavement.

Tests were run on the TER using a 37,000-pound two-axle dump truck. At 56 mph, the truck traveled approximately 300 feet into the TER. The following conclusions were reached:

- Average deceleration was comparable to a panic stop on dry pavement.
- Narrowing the chute width may prevent excessive yaw and jack-knifing.
- Tow anchors may be necessary to remove heavy vehicles from arresting material.
- Minimal post-impact maintenance was required.

3.2.6 Conclusions

Whether researching federal or state agencies, or reviewing literature online, it is apparent that there is no clear cut guidelines that are widely accepted for the determination of need, location and design of TERs. While some distributors are pushing cutting edge technology such as arresting dragnets, most agencies are relying heavily on documents published several years ago, namely the NCHRP *Synthesis of Highway Practice 178 – Truck Escape Ramps* and the AASHTO A Policy on Geometric Design of Highways and Streets. Caltrans has published its own set of guidelines for the development of TERs within the State of California, *Design Guide for Truck Escape Ramps*. Similarly, the Arizona Department of Transportation (ADOT) has compiled a rather extensive collection of research and policy reports dating back to the early 1980s.

The implementation of TERs across the country is becoming more and more common. In most States they are located in rural areas with long, steep downgrades and a curved horizontal geometry, but urban areas with high densities of vehicles and development are also being considered as potential sites for TERs due to the catastrophic outcome of a runaway truck in these areas.

The preferred type of TER is the arrester bed, while most agencies do state that location and type depends a great deal on topography. Geometrics very greatly from State to State, and even within individual States as the research of Arizona policies have shown.

3.3 Conclusions

The purpose of the data gathering process in both *Chapter 2 – Evaluation of Conditions at Existing Truck Escape Ramp (TER) Sites* and above was to better understand the current practices in Arizona as well as other States with respect to truck escape ramp (TER) need, location and design.

The review of researched information above indicates that the State of Arizona, in its current practices with respect to the establishment of truck escape ramps (TERs), is in-line with other State Departments of Transportation in their methods of determining need and location, as well as in their design standards.

The next step in the Study will be to research potential TER sites as recommended by the various Districts with respect to current criteria published in the ADOT *Roadway Design Guidelines*.

Chapter 4
Evaluation of Conditions at Potential Truck Escape Ramp (TER) Locations

4.1 Evaluation Criteria

This chapter will focus on the evaluation of potential new TER sites. The Arizona Department of Transportation's (ADOT) *Roadway Design Guidelines*, will be used as a guide in our evaluation.

Chapter 2*, Evaluation of Conditions at Existing Truck Escape Ramp (TER) Sites*, lists the potential TER sites identified by the District Engineers (See **Table 4.1.1**).

Table 4.1.1
Potentially Needed and Planned TERs

District	Potentially Needed TER Location	Planned/Designed TER
Flagstaff	None	None
Globe	US 60 WB (MP 280)	US 60 WB (MP 280+/-)
Holbrook	None	None
Kingman	None	SR 68 WB (MP 5.75)
Phoenix	SR 87 (MP 215)	None
Prescott	SR 87 NB (MP 230) SR 260 WB (MP 232)	None
Safford	US 191 SB (MP 166) US 191 NB (MP 153) SR 78 SB (MP 153) SR 80 leaving Bisbee	None
Tucson	SR 83 NB (MP 42)	None
Yuma	I-8 EB (MP 20)	None

Chapter 3, *Documenting the State of the Practice*, provides a detailed review of Federal, state and organizational research into the development of TERs. This review shows that ADOT's policy for need, location and design is consistent with current policy across the country.

The ADOT *Roadway Design Guidelines* state that the determination of need relies on three considerations:

1. The number of accidents that occur in conjunction with a long sustained downgrade.
2. Information obtained from professional truck drivers, wrecker operators, Department of Public Safety officers and by inspection of accident data.
3. Areas where the combination of percent downgrade and length of downgrade exceed the curve presented in Figure 209.4A of the *Roadway Design Guidelines*.

4.2 Evaluation of Potential Project Locations

The 10 locations listed in the table above will be evaluated to determine percent and length of downgrade, accident history and average daily traffic (ADT) in accordance with information presented in the ADOT *Roadway Design Guidelines*. Additionally, the two TERs that have already begun the design process will also be analyzed to determine similar factors.

4.2.1 Potential Project Location 1 – US Route 60 WB (MP 280): Salt River Canyon

The Globe District identified the area surrounding MP 280 on US Route 60 WB as a potential site for a truck escape ramp (TER). **Table 4.2.1** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.1
US Route 60 WB Location

US Route 60 WB Location, US 60 MP 280	
Variable	**Description**
Mainline Station Range	Sta. 384+00.00 (east) to Sta. 1213+50.00 (west)
Milepost Range (approximate)	MP 289.04 (east) to MP 274.74 (west)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 384+00.00 (MP 289.04), +6.0000%, 0.73miles Sta. 345+50.00 (MP 288.31), -3.0610%, 0.37 miles Sta. 326+00.00 (MP 287.75), +0.8132%, 0.28 miles Sta. 320+00.00 = Sta. 1890+57.18 (MP 287.64) Sta. 1882+00.00 (MP 287.48), -1.6000%, 0.19 miles Sta. 1872+00.00 (MP 287.29), +5.0000%, 0.44 miles Sta. 1849+00.00 (MP 286.85), +6.5000%, 0.51 miles Sta. 1822+00.00 (MP 286.34), +6.2500%, 0.42 miles Sta. 1800+00.00 (MP 285.92), +6.0000%, 0.38 miles Sta. 1780+00.00 (MP 285.54), +6.3600%, 0.66 miles Sta. 1745+00.00 (MP 284.81), +2.6300%, 0.27 miles Sta. 1731+00.00 (MP 284.54), +5.9700%, 0.36 miles Sta. 1712+00.00 (MP 284.18), +1.7000%, 0.45 miles Sta. 1688+00.00 (MP 283.73), -2.8477%, 0.42 miles Sta. 1666+00.00 (MP 283.31), +4.5000%, 0.25 miles Sta. 1653+00.00 (MP 283.06), +0.5000%, 0.25 miles Sta. 1640+00.00 (MP 282.80), +5.7500%, 0.23 miles Sta. 1628+00.00 (MP 282.57), +3.0000%, 0.49 miles Sta. 1602+00.00 (MP 282.08), +0.2927%, 0.39 miles Sta. 1581+50.00 (MP 281.70), -6.0000%, 0.33 miles Sta. 1564+00.00 (MP 281.36), -1.0000%, 0.17 miles Sta. 1555+00.00 (MP 281.19), -3.7500%, 0.42 miles Sta. 1533+00.00 (MP 280.78), +2.4750%, 0.38 miles Sta. 1513+00.00 (MP 280.40), +2.6667%, 0.23 miles Sta. 1501+00.00 (MP 280.17), +1.2222%, 0.17 miles

Vertical Geometry (Continued) (Including: station, milepost, grade and length.)	Sta. 1492+00.00 (MP 280.00), +4.0455%, 0.21 miles Sta. 1481+00.00 (MP 279.80), +0.9231%, 0.25 miles Sta. 1468+00.00 (MP 279.56), +2.5500%, 0.19 miles Sta. 1458+00.00 (MP 279.37), +2.7917%, 0.23 miles Sta. 1446+00.00 (MP 279.14), +3.4000%, 0.91 miles Sta. 1398+00.00 (MP 278.46), -6.5000%, 1.10 miles Sta. 1340+00.00 (MP 277.36), -7.0000%, 0.19 miles Sta. 1330+00.00 (MP 277.17), -6.3400%, 0.11 miles Sta. 1324+00.00 (MP 277.06), -2.4574%, 0.36 miles Sta. 1305+00.00 (MP 276.70), -2.6073%, 0.34 miles Sta. 1287+25.00 (MP 276.36), -6.0000%, 0.38 miles Sta. 1267+00.00 (MP 275.98), -5.5000%, 0.19 miles Sta. 1257+00.00 (MP 275.79), -6.0000%, 0.32 miles Sta. 1240+00.00 (MP 275.46), -5.2500%, 0.17 miles Sta. 1231+00.00 (MP 275.29), -5.0000%, 0.25 miles Sta. 1218+00.00 (MP 275.05), -5.2500%, 0.30 miles Sta. 1202+00.00 (MP 274.74), -3.2500%
Annual Average Daily Traffic (AADT)	2752 (Year 2000)
Percent Trucks	3.78 (Year 2000, 15.66 Year 1998)
Average Number of Accidents per Year	22.7 Total (0.7 Truck)

Number of Accidents - Crash data for US Route 60 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 289.04 (east) to MP 274.74 (west)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 68 (22.7 per year) and the total truck crashes were 2 (0.7 per year). The first harmful event in the truck crashes included: 2 collisions with other motor vehicles.

Relationship of Percent Downgrade and Length of Downgrade - There are two segments along US Route 60 which exceed the curve presented in Figure 209.4A (*Roadway Design Guidelines*). The first segment is approximately located between MP 275 and MP 279 in the westbound direction. With a total length of 3.71 miles and an average downgrade of –5.2641%, this segment meets the determination of need for this particular consideration.

Additionally, the segment approximately located between MP 284 and MP 287 in the eastbound direction also meets the determination of need for this particular consideration. The segment has a total length of 3.48 miles and an average downgrade of –5.0513%.

4.2.2 Potential Project Location 2 – State Route 87 SB (MP 215): Sunflower to Four-Peaks

The Phoenix District identified the area surrounding MP 215 on SR87 SB as a potential site for a truck escape ramp (TER). **Table 4.2.2** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.2
State Route 87 SB Location

State Route 87 SB Location, SR 87 MP 215	
Variable	**Description**
Mainline Station Range	Sta. 2237+00.00 (south) to Sta. 166+00.00 (north)
Milepost Range (Approximate)	MP 213.57 (south) to MP 232.67 (north)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 2219+00.00 (MP 212.96), +4.7500%, 0.36 miles Sta. 2238+00.00 (MP 213.32), +3.5000%, 0.21 miles Sta. 2249+00.00 (MP 213.53), +6.5000%, 0.37 miles Sta. 2268+40.00 (MP 213.90), +1.1770%, 0.13 miles Sta. 2275+41.00 (MP 214.03), +7.0000%, 0.47 miles Sta. 2300+00.00 (MP 214.49), +6.8000%, 0.19 miles Sta. 2310+00.00 (MP 214.68), +7.0000%, 0.31 miles Sta. 2326+50.00 (MP 215.00), +1.4007%, 0.17 miles Sta. 2336+70.43 = Sta. 2331+29.72 (MP 215.19) Sta. 2335+40.00 (MP 215.27), +6.9860%. 0.27 miles Sta. 2349+50.00 (MP 215.54), +4.3867%, 0.37 miles Sta. 2369+00.00 (MP 215.91), +7.0000%, 0.24 miles Sta. 2381+60.00 (MP 216.14), +1.6861%, 0.17 miles Sta. 2390+60.00 (MP 216.31), +6.9583%, 0.21 miles Sta. 2396+14.71 = Sta. 2395+82.17 (MP 216.42) Sta. 2401+50.00 (MP 216.53), +5.3500%, 0.36 miles Sta. 2420+50.00 (MP 216.86), -4.4895%, 0.22 miles Sta. 2432+12.00 (MP 217.11), +4.1861%, 0.23 miles Sta. .2444+50.00 (MP 217.35), +6.0000%, 0.25 miles Sta. 2452+09.85 = Sta. 2454+66.92 (MP 217.49) Sta. 2457+75.00 (MP 217.55), -6.9683%, 0.38 miles Sta. 2477+95.00 (MP 217.93), -2.2500%, 0.45 miles Sta. 2501+50.00 (MP 218.37), +1.0000%, 0.22 miles Sta. 2513+00.00 (MP 218.59), +1.3000%, 0.23 miles Sta. 2525+00.00 (MP 218.82), +1.0412%, 0.48 miles Sta. 2550+50.00 (MP 219.30), +2.1200%, 0.26 miles Sta. 2564+00.00 (MP 219.56), +1.5000%, 0.23 miles Sta. 2576+00.00 (MP 219.78), +1.4286%, 0.27 miles Sta. 2590+00.00 (MP 220.05), +3.5889%, 0.21 miles Sta. 2601+00.00 (MP 220.26), +0.2896%, 0.36 miles Sta. 2620+00.00 (MP 220.62), +1.9410%, 0.16 miles Sta. 2628+50.00 (MP 220.78), +3.4000%, 0.19 miles Sta. 2638+50.00 (MP 220.97), +6.0000%, 0.27 miles

Vertical Geometry (Continued) (Including: station, milepost, grade and length.)	Sta. 2652+50.00 (MP 221.23), -4.8200%, 0.23 miles Sta. 2664+50.00 (MP 221.46), +1.8640%, 0.45 miles Sta. 2669+47.32 = Sta. 2710+33.75 (MP 221.55) Sta. 2729+00.00 (MP 221.90), +1.1000%, 0.19 miles Sta. 2739+00.00 (MP 222.09), +3.0420%, 0.23 miles Sta. 2751+00.00 (MP 222.32), +0.6500%, 0.19 miles Sta. 2761+00.00 (MP 222.51), +6.5000%, 0.40 miles Sta. 2782+00.00 (MP 222.91), +2.5000%, 0.25 miles Sta. 2795+00.00 (MP 223.15), +5.8370%, 0.51 miles Sta. 2822+00.00 (MP 223.66), +1.6000%, 0.24 miles Sta. 2834+50.00 (MP 223.90), +4.4614%, 0.41 miles Sta. 2856+00.00 (MP 224.31), +5.5000%, 0.24 miles Sta. 2868+59.58 (MP 224.55), +0.9635%, 0.11 miles Sta. 2868+59.59 = Sta. 594+51.69 (MP 224.55) Sta. 588+50.00 (MP 224.66), +5.6000%, 0.28 miles Sta. 573+50.00 (MP 224.95), -6.8900%, 0.29 miles Sta. 558+00.00 (MP 225.24), -6.5000%, 0.23 miles Sta. 546+00.00 (MP 225.47), -5.5000%, 0.18 miles Sta. 536+50.00 (MP 225.65), -6.5000%, 0.52 miles Sta. 509+00.00 (MP 226.17), -6.4760%, 0.28 miles Sta. 494+45.00 (MP 226.45), -6.5000%, 0.48 miles Sta. 469+00.00 (MP 226.93), -7.0000%, 0.33 miles Sta. 451+50.00 (MP 227.26), -5.0000%, 0.43 miles Sta. 429+00.00 (MP 227.68), -6.5000%, 0.23 miles Sta. 417+00.00 (MP 227.91), -4.5700%, 0.13 miles Sta. 410+00.00 (MP 228.04), -6.0000%, 0.33 miles Sta. 392+50.00 (MP 228.38), -3.0000%, 0.29 miles Sta. 377+00.00 (MP 228.67), +7.0000%, 0.28 miles Sta. 362+00.00 (MP 228.95), +1.7070%, 0.16 miles Sta. 352+50.00 (MP 229.11), +5.7500%, 0.26 miles Sta. 340+00.00 (MP 229.37), -6.5000%, 0.20 miles Sta. 329+70.00 (MP 229.57), +1.5770%, 0.24 miles Sta. 317+00.00 (MP 229.81), +6.5220%, 0.16 miles Sta. 308+50.00 (MP 229.97), +5.1260%, 0.14 miles Sta. 301+35.00 (MP 230.10), +6.8330%, 0.21 miles Sta. 290+50.00 (MP 230.31), +2.8000%, 0.20 miles Sta. 280+00.00 (MP 230.51), +6.2235%, 0.32 miles Sta. 263+00.00 (MP 230.83), +4.5710%, 0.13 miles Sta. 256+00.00 (MP 230.96), +7.0000%, 0.13 miles Sta. 249+00.00 (MP 231.09), +4.9810%, 0.13 miles Sta. 242+00.00 (MP 231.23), +3.8500%, 0.27 miles Sta. 228+00.00 (MP 231.49), +4.7371%, 0.20 miles Sta. 217+50.00 (MP 231.69), -6.0000%, 0.27 miles Sta. 203+00.00 (MP 231.97), -5.5000%, 0.37 miles Sta. 183+40.00 (MP 232.34), -6.9700%, 0.18 miles Sta. 173+75.00 (MP 232.52), -4.8500%, 0.15 miles Sta. 166+00.00 (MP 232.67), -6.2410%
Annual Average Daily Traffic (AADT)	10415 (Year 2000)
Percent Trucks	6.43 (Year 2000)
Average Number of Accidents per Year	Total 119.3 (5.0 Trucks)

Number of Accidents - Crash data for State Route 87 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 213.57 (south) to MP 232.67 (north)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 358 (119.3 per year) and the total truck crashes were 15 (5.0 per year). The first harmful event in the truck crashes included: 10 collisions with other motor vehicle, 2 overturning, 1 other fixed object, 1 fire in vehicle, and 1 object dropped from vehicle.

Relationship of Percent Downgrade and Length of Downgrade - There are two segments along State Route 87 which exceed the curve presented in Figure 209.4A (*Roadway Design Guidelines*). The first segment is approximately located between MP 213 and MP 216.5 in the southbound direction. The segment has a total length of 3.82 miles and an average downgrade of –5.0353%.

The second segment is presented below, in **Section 4.2.3**.

4.2.3 Potential Project Location 3 – State Route 87 NB (MP 230): Slate Creek

The Prescott District identified the area surrounding MP 230 on SR 87 NB as a potential site for a truck escape ramp (TER). **Table 4.2.3** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.3
State Route 87 NB Location

State Route 87 NB Location, SR 87 MP 230	
Variable	**Description**
Mainline Station Range	Sta. 2237+00.00 (south) to Sta. 166+00.00 (north)
Milepost Range (Approximate)	MP 213.57 (south) to MP 232.67 (north)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 2219+00.00 (MP 212.96), +4.7500%, 0.36 miles Sta. 2238+00.00 (MP 213.32), +3.5000%, 0.21 miles Sta. 2249+00.00 (MP 213.53), +6.5000%, 0.37 miles Sta. 2268+40.00 (MP 213.90), +1.1770%, 0.13 miles Sta. 2275+41.00 (MP 214.03), +7.0000%, 0.47 miles Sta. 2300+00.00 (MP 214.49), +6.8000%, 0.19 miles Sta. 2310+00.00 (MP 214.68), +7.0000%, 0.31 miles Sta. 2326+50.00 (MP 215.00), +1.4007%, 0.17 miles

Vertical Geometry (Continued) (Including: station, milepost, grade and length.)	Sta. 2336+70.43 = Sta. 2331+29.72 (MP 215.19) Sta. 2335+40.00 (MP 215.27), +6.9860%. 0.27 miles Sta. 2349+50.00 (MP 215.54), +4.3867%, 0.37 miles Sta. 2369+00.00 (MP 215.91), +7.0000%, 0.24 miles Sta. 2381+60.00 (MP 216.14), +1.6861%, 0.17 miles Sta. 2390+60.00 (MP 216.31), +6.9583%, 0.21 miles Sta. 2396+14.71 = Sta. 2395+82.17 (MP 216.42) Sta. 2401+50.00 (MP 216.53), +5.3500%, 0.36 miles Sta. 2420+50.00 (MP 216.86), -4.4895%, 0.22 miles Sta. 2432+12.00 (MP 217.11), +4.1861%, 0.23 miles Sta. .2444+50.00 (MP 217.35), +6.0000%, 0.25 miles Sta. 2452+09.85 = Sta. 2454+66.92 (MP 217.49) Sta. 2457+75.00 (MP 217.55), -6.9683%, 0.38 miles Sta. 2477+95.00 (MP 217.93), -2.2500%, 0.45 miles Sta. 2501+50.00 (MP 218.37), +1.0000%, 0.22 miles Sta. 2513+00.00 (MP 218.59), +1.3000%, 0.23 miles Sta. 2525+00.00 (MP 218.82), +1.0412%, 0.48 miles Sta. 2550+50.00 (MP 219.30), +2.1200%, 0.26 miles Sta. 2564+00.00 (MP 219.56), +1.5000%, 0.23 miles Sta. 2576+00.00 (MP 219.78), +1.4286%, 0.27 miles Sta. 2590+00.00 (MP 220.05), +3.5889%, 0.21 miles Sta. 2601+00.00 (MP 220.26), +0.2896%, 0.36 miles Sta. 2620+00.00 (MP 220.62), +1.9410%, 0.16 miles Sta. 2628+50.00 (MP 220.78), +3.4000%, 0.19 miles Sta. 2638+50.00 (MP 220.97), +6.0000%, 0.27 miles Sta. 2652+50.00 (MP 221.23), -4.8200%, 0.23 miles Sta. 2664+50.00 (MP 221.46), +1.8640%, 0.45 miles Sta. 2669+47.32 = Sta. 2710+33.75 (MP 221.55) Sta. 2729+00.00 (MP 221.90), +1.1000%, 0.19 miles Sta. 2739+00.00 (MP 222.09), +3.0420%, 0.23 miles Sta. 2751+00.00 (MP 222.32), +0.6500%, 0.19 miles Sta. 2761+00.00 (MP 222.51), +6.5000%, 0.40 miles Sta. 2782+00.00 (MP 222.91), +2.5000%, 0.25 miles Sta. 2795+00.00 (MP 223.15), +5.8370%, 0.51 miles Sta. 2822+00.00 (MP 223.66), +1.6000%, 0.24 miles Sta. 2834+50.00 (MP 223.90), +4.4614%, 0.41 miles Sta. 2856+00.00 (MP 224.31), +5.5000%, 0.24 miles Sta. 2868+59.58 (MP 224.55), +0.9635%, 0.11 miles Sta. 2868+59.59 = Sta. 594+51.69 (MP 224.55) Sta. 588+50.00 (MP 224.66), +5.6000%, 0.28 miles Sta. 573+50.00 (MP 224.95), -6.8900%, 0.29 miles Sta. 558+00.00 (MP 225.24), -6.5000%, 0.23 miles Sta. 546+00.00 (MP 225.47), -5.5000%, 0.18 miles Sta. 536+50.00 (MP 225.65), -6.5000%, 0.52 miles Sta. 509+00.00 (MP 226.17), -6.4760%, 0.28 miles Sta. 494+45.00 (MP 226.45), -6.5000%, 0.48 miles Sta. 469+00.00 (MP 226.93), -7.0000%, 0.33 miles Sta. 451+50.00 (MP 227.26), -5.0000%, 0.43 miles Sta. 429+00.00 (MP 227.68), -6.5000%, 0.23 miles Sta. 417+00.00 (MP 227.91), -4.5700%, 0.13 miles

Vertical Geometry (Continued) (Including: station, milepost, grade and length.)	Sta. 410+00.00 (MP 228.04), -6.0000%, 0.33 miles Sta. 392+50.00 (MP 228.38), -3.0000%, 0.29 miles Sta. 377+00.00 (MP 228.67), +7.0000%, 0.28 miles Sta. 362+00.00 (MP 228.95), +1.7070%, 0.16 miles Sta. 352+50.00 (MP 229.11), +5.7500%, 0.26 miles Sta. 340+00.00 (MP 229.37), -6.5000%, 0.20 miles Sta. 329+70.00 (MP 229.57), +1.5770%, 0.24 miles Sta. 317+00.00 (MP 229.81), +6.5220%, 0.16 miles Sta. 308+50.00 (MP 229.97), +5.1260%, 0.14 miles Sta. 301+35.00 (MP 230.10), +6.8330%, 0.21 miles Sta. 290+50.00 (MP 230.31), +2.8000%, 0.20 miles Sta. 280+00.00 (MP 230.51), +6.2235%, 0.32 miles Sta. 263+00.00 (MP 230.83), +4.5710%, 0.13 miles Sta. 256+00.00 (MP 230.96), +7.0000%, 0.13 miles Sta. 249+00.00 (MP 231.09), +4.9810%, 0.13 miles Sta. 242+00.00 (MP 231.23), +3.8500%, 0.27 miles Sta. 228+00.00 (MP 231.49), +4.7371%, 0.20 miles Sta. 217+50.00 (MP 231.69), -6.0000%, 0.27 miles Sta. 203+00.00 (MP 231.97), -5.5000%, 0.37 miles Sta. 183+40.00 (MP 232.34), -6.9700%, 0.18 miles Sta. 173+75.00 (MP 232.52), -4.8500%, 0.15 miles Sta. 166+00.00 (MP 232.67), -6.2410%, 0.13 miles Sta. 159+00.00 (MP 232.80), -4.7850%, 0.32 miles Sta. 152+62.24 = Sta. 149+04.97 (MP 232.92) Sta. 142+00.00 (MP 233.05), +6.6350%, 0.26 miles Sta. 128+30.00 (MP 233.31), -6.9730%, 0.44 miles Sta. 105+00.00 (MP 233.75), -2.2800%, 0.12 miles Sta. 98+50.00 (MP 233.88), -4.2480%, 0.11 miles Sta. 92+50.00 (MP 233.99), -1.1000%, 0.13 miles Sta. 85+70.00 (MP 234.12), -5.1800%, 0.14 miles Sta. 78+20.00 (MP 234.26), +0.5320%, 0.26 miles Sta. 64+45.00 (MP 234.52), -7.0000%, 0.16 miles Sta. 56+20.00 (MP 234.68), +1.1400%, 0.14 miles Sta. 48+70.00 (MP 234.82), -6.2500%, 0.23 miles Sta. 36+60.00 (MP 235.05), +5.6050%, 0.18 miles Sta. 27+30.00 (MP 235.23), -1.7000%, 0.21 miles Sta. 16+00.00 (MP 235.44), +6.5000%, 0.14 miles Sta. 8+50.00 (MP 235.58), +2.9730%, 0.11 miles Sta. 2+50.00 (MP 235.70), +5.2930%
Annual Average Daily Traffic (AADT)	10415 (Year 2000)
Percent Trucks	6.43 (Year 2000)
Average Number of Accidents per Year	119.3 Total (5.0 Trucks)

Number of Accidents - Crash data for State Route 87 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 213.57 (south) to MP 232.67 (north)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 358 (119.3 per year) and the total truck crashes were 15 (5.0 per year). The first harmful event in the truck crashes included: 10 collisions with other motor vehicle, 2 overturning, 1 other fixed object, 1 fire in vehicle, and 1 object dropped from vehicle.

Relationship of Percent Downgrade and Length of Downgrade - As stated above in Section 3.2.2, there are two segments of State Route 87 which exceed the curve in Figure 209.4A (*Roadway Design Guidelines*). The first segment, as described above, is in the southbound direction between MP 213 and MP 216.5.

The second segment, which exceeds the curve in Figure 209.4A is approximately located between MP 225 and MP 228.5 in the northbound direction. This segment has an average downgrade of –5.8697% over a total length of 3.72 miles.

Additionally, there were many segments which had steep grades ranging from –4% to almost –6%, but did not have the necessary length to become warranted under Figure 209.4A.

4.2.4 Potential Project Location 4 – State Route 260 WB (MP 232): Verde Valley

The Prescott District identified the area surrounding MP 232 on SR 260 WB as a potential site for a truck escape ramp (TER). **Table 4.2.4** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.4
State Route 260 WB Location

State Route 260 WB Location, SR 260 232	
Variable	**Description**
Mainline Station Range	Sta. 321+50.00 to Sta. 592+00.00
Milepost Range (Approximate)	MP 231.62 to MP 236.75
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 321+50.00 (MP 231.62), -0.5000%, 0.02 miles Sta. 351+00.00 (MP 232.18), -1.3000%, 0.56 miles Sta. 363+00.00 (MP 232.41), -2.0250%, 0.23 miles Sta. 377+00.00 (MP 232.67), -4.5000%, 0.27 miles Sta. 390+00.00 (MP 232.92), -2.2700%, 0.25 miles Sta. 412+50.00 (MP 233.35), -6.5107%, 0.43 miles Sta. 424+00.00 (MP 233.56), -5.7826%, 0.22 miles Sta. 439+00.00 (MP 233.85), -7.0000%, 0.28 miles Sta. 456+00.00 (MP 234.17), -2.0303%, 0.32 miles Sta. 478+50.00 (MP 234.60), -6.7800%, 0.43 miles
Vertical Geometry (Continued) (Including: station, milepost, grade and length.)	Sta. 490+00.00 (MP 234.81), -5.0183%, 0.22 miles Sta. 570+00.00 (MP 236.33), -6.9999%, 1.52 miles Sta. 585+50.00 (MP 236.62), -2.0832%, 0.29 miles Sta. 592+00.00 (MP 236.75), -6.5000%, 0.12 miles
Annual Average Daily Traffic (AADT)	6500 (Year 2000)
Percent Trucks	18.78 (Year 2000)
Average Number of Accidents per Year	25.0 Total (0.0 Trucks)

Number of Accidents -Crash data for State Route 260 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 220.0 (west) to MP 240.0

(east)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 75 (25.0 per year) and the total truck crashes were 0 (0.0 per year).

Relationship of Percent Downgrade and Length of Downgrade- There is one segment along State Route 260 which exceeds the curve presented in Figure 209.4A (*Roadway Design Guidelines*). The segment is approximately located between MP 232 and MP 237 in the westbound direction. With a total length of 5.15 miles and an average downgrade of –4.2357%, this segment meets the determination of need for this particular consideration.

4.2.5 Potential Project Location 5 – US Route 191 SB (MP 166): Horseshoe Curve

The Safford District identified the area surrounding MP 166 on US 191 SB as a potential site for a truck escape ramp (TER). **Table 4.2.5** shows ADT, percent trucks and accident summary. As-built information was not available from the District.

Table 4.2.5
US Route 191 SB Location

US Route 191 SB Location, US 191 MP 166	
Variable	**Description**
Mainline Station Range	Not Available
Milepost Range (Approximate)	Not Available
Vertical Geometry (Including: station, milepost, grade and length.)	Not Available
Annual Average Daily Traffic (AADT)	2630 (Year 2000)
Percent Trucks	11.90 (Year 2000)
Average Number of Accidents per Year	17.7 Total (1.3 Trucks)

Number of Accidents - Crash data for US Route 191 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 53 (17.7 per year) and the total truck crashes were 4 (1.3 per year). The first harmful event in the truck crashes included: 4 collisions with other motor vehicle.

Relationship of Percent Downgrade and Length of Downgrade- No information was available from the District.

4.2.6 Potential Project Location 6 – US Route 191 NB (MP 153): Three Way

The Safford District identified the area surrounding MP 153 on US 191 NB as a potential site for a truck escape ramp (TER). **Table 4.2.6** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.6
US Route 191 NB Location

US Route 191 NB Location, US 191 MP 153	
Variable	**Description**
Mainline Station Range	Sta. 698+50.00 (south) to Sta. 1263+00.00 (north)
Milepost Range (Approximate)	MP 144.26 (south) to MP 155.00 (north)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 698+50.00 (MP 144.26), +1.0000%, 0.22 miles Sta. 710+00.00 (MP 144.48), +0.0000%, 0.08 miles Sta. 714+00.00 (MP 144.56), +2.3000%, 0.12 miles Sta. 720+50.00 (MP 144.68), +1.1010%, 0.19 miles Sta. 730+50.00 (MP 144.87), +4.0000%, 0.13 miles Sta. 737+50.00 (MP 145.00), +1.1600%, 0.16 miles Sta. 746+00.00 (MP 145.16), +3.3060%, 0.13 miles Sta. 753+00.00 (MP 145.30), +1.0000%, 0.19 miles Sta. 763+00.00 (MP 145.49), +4.0000%, 0.13 miles Sta. 770+00.00 (MP 145.62), +1.5500%, 0.38 miles Sta. 790+00.00 (MP 146.00), +5.9040%, 0.13 miles Sta. 793+29.60 = Sta. 793+18.24 (MP 146.06) Sta. 797+00.00 (MP 146.14), +2.9400%, 0.14 miles Sta. 804+50.00 (MP 146.28), +4.3000%, 0.12 miles Sta. 811+00.00 (MP 146.40), -0.1430%, 0.13 miles Sta. 818+00.00 (MP 146.53), +5.0000%, 0.21 miles Sta. 829+00.00 (MP 146.74), +2.5000%, 0.30 miles Sta. 845+00.00 (MP 147.05), -2.8000%, 0.28 miles Sta. 860+00.00 (MP 147.33), +1.0000%, 0.19 miles Sta. 870+00.00 (MP 147.52), -5.2500%, 0.15 miles Sta. 878+00.00 (MP 147.67), -3.5330%, 0.28 miles Sta. 893+00.00 (MP 147.95), -1.2857%, 0.11 miles Sta. 899+00.00 (MP 148.07), -3.3700%, 0.32 miles Sta. 916+00.00 (MP 148.39), -1.7500%, 0.23 miles Sta. 928+00.00 (MP 148.62), -4.6200%, 0.26 miles Sta. 941+50.00 (MP 148.87), -0.4910%, 0.26 miles Sta. 955+00.00 (MP 149.13), -7.0000%, 0.25 miles Sta. 968+00.00 (MP 149.38), -2.7500%, 0.31 miles Sta. 984+50.00 (MP 149.69), -1.4650%, 0.18 miles Sta. 994+00.00 (MP 149.87), -1.1000%, 0.27 miles Sta. 1008+50.00 (MP 150.14), -7.5000%, 0.16 miles Sta. 1017+00.00 (MP 150.30), -0.3000%, 0.12 miles Sta. 1023+50.00 (MP 150.43), -3.1750%, 0.11 miles Sta. 1029+50.00 (MP 150.54), -1.0000%, 0.27 miles Sta. 1044+00.00 (MP 150.81), -0.4500%, 0.19 miles Sta. 1054+00.00 (MP 151.00), -0.9000%, 0.19 miles Sta. 1064+00.00 (MP 151.19), +1.8750%, 0.15 miles Sta. 1072+00.00 (MP 151.34), -2.2000%, 0.37 miles Sta. 1091+50.00 (MP 151.71), -6.0000%, 0.24 miles Sta. 1104+00.00 (MP 151.95), -6.5000%, 0.15 miles Sta. 1112+00.00 (MP 152.10), -6.0000%, 0.15 miles

	Sta. 1120+00.00 (MP 152.25), -6.5000%, 0.17 miles Sta. 1129+00.00 (MP 152.42), -3.1360%, 0.21 miles Sta. 1140+00.00 (MP 152.63), -7.0000%, 0.25 miles Sta. 1153+00.00 (MP 152.88), -6.0000%, 0.57 miles Sta. 1183+00.00 (MP 153.45), -7.0000%, 0.55 miles Sta. 1211+83.01 (MP 153.99), +6.0000%, 0.38 miles Sta. 1231+78.00 (MP 154.37), +1.0000%, 0.25 miles Sta. 1245+00.00 (MP 154.62), +0.6220%, 0.17 miles Sta. 1254+00.00 (MP 154.79), +2.0710%, 0.17 miles Sta. 1263+500.00 (MP 154.96), -2.1310%
Annual Average Daily Traffic (AADT)	2630 (Year 2000)
Percent Trucks	11.90 (Year 2000)
Average Number of Accidents per Year	43.3 Total (1.7 Trucks)

Number of Accidents - Crash data for US Route 191 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 144.26 (south) to MP 155.00 (north)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 130 (43.3 per year) and the total truck crashes were 5 (1.7 per year). The first harmful event in the truck crashes included: 2 collisions with other motor vehicle, 1 overturning, 1 collision with guardrail, and 1 object dropped from vehicle.

Relationship of Percent Downgrade and Length of Downgrade - There is one segment along US Route 191 which exceeds the curve presented in Figure 209.4A (*Roadway Design Guidelines*). The segment is approximately located between MP 152 and MP 153.5 in the northbound direction. The segment has a total length of 2.28 miles and an average downgrade of –6.0170%.

4.2.7 Potential Project Location 7 – US Route 191 NB at Smelter Hill

The Safford District identified the area surrounding MP 153 on US 191 NB as a potential site for a truck escape ramp (TER). District personnel have indicated that this potential location is the same as the location presented in **Section 4.2.6** above. Refer to **Section 4.2.6** for additional information.

4.2.8 Potential Project Location 8 – State Route 78 SB (MP 153)

The Safford District identified the area surrounding MP 153 on SR 78 SB as a potential site for a truck escape ramp (TER). **Table 4.2.7** shows the ADT, percent trucks and accident summary. As-built information was not available from the District.

Table 4.2.7
State Route 78 SB Location

State Route 78 SB Location, SR 78 MP 153	
Variable	**Description**
Mainline Station Range	Not Available
Milepost Range (Approximate)	Not Available
Vertical Geometry (Including: station, milepost, grade and length.)	Not Available
Annual Average Daily Traffic (AADT)	392 (Year 2000)
Percent Trucks	11.90 (Year 2000)
Average Number of Accidents per Year	4.33 Total (0.33 Truck)

Number of Accidents - Crash data for State Route 78 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 13 (4.33 per year) and the total truck crashes were 1 (0.33 per year).

Relationship of Percent Downgrade and Length of Downgrade - No information was available from the District.

4.2.9 Potential Project Location 9 – State Route 80 leaving Bisbee

The Safford District originally identified an area along SR 80 as a potential site for a truck escape ramp (TER). Further analysis by the District has lead to the conclusion that this segment of SR 80 would better be served by an uphill climbing lane for truck traffic rather than a truck escape ramp for downhill traffic.

4.2.10 Potential Project Location 10 – State Route 83 NB (MP 42)

The Tucson District identified the area surrounding MP 42 on SR 83 NB as a potential site for a truck escape ramp (TER). **Table 4.2.8** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.8
State Route 83 NB Location

State Route 83 NB Location, SR 83 MP 42	
Variable	**Description**
Mainline Station Range	Sta. 128+50.00 (south) to 142+00.00 (north) (Multiple station equations between.)
Milepost Range (Approximate)	MP 35.61 (south) to MP 46.20 (north)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 128+50.00 (MP 35.61), -3.6000%, 0.37 miles Sta. 148+00.00 (MP 35.98), +1.4000%, 0.34 miles Sta. 166+00.00 (MP 36.32), -5.0000%, 0.30 miles Sta. 182+00.00 (MP 36.62), +1.6000%, 0.28 miles Sta. 197+00.00 (MP 36.91), -4.1400%, 0.32 miles Sta. 214+00.00 (MP 37.24), +3.1230%, 0.89 miles Sta. 261+00.00 (MP 38.13), -1.8020%, 0.39 miles Sta. 281+50.00 (MP 38.52), +2.1720%, 0.41 miles Sta. 303+00.00 (MP 38.93), +2.5517%, 0.55 miles Sta. 332+00.00 (MP 39.47), +0.2683%, 0.78 miles Sta. 373+00.00 (MP 40.25), -4.0590%, 0.41 miles Sta. 394+50.00 (MP 40.66), +2.0000%, 0.26 miles Sta. 408+00.00 (MP 40.91), +3.4764%, 0.31 miles Sta. 424+50.00 (MP 41.23), +1.6261%, 0.37 miles Sta. 444+00.00 (MP 41.60), +5.1725%, 0.63 miles Sta. 477+50.00 (MP 42.23), +3.4000%, 0.35 miles Sta. 513+80.33 = 514+22.49 (MP 42.92) Sta. 521+00.00 (MP 43.05), +3.6800%, 0.47 miles Sta. 537+00.00 (MP 43.35), -4.5000%, 0.30 miles Sta. 549+20.76 = 3+30.46 (MP 43.58) Sta. 11+00.00 (MP 43.73), -5.0000%, 0.38 miles Sta. 19+00.00 (MP 43.88), -5.8000%, 0.30 miles Sta. 35+00.00 (MP 44.18), -6.2000%, 0.31 miles Sta. 51+50.00 (MP 44.50), +0.5930%, 0.21 miles Sta. 62+50.00 (MP 44.71), -5.0000%, 0.30 miles Sta. 63+81.81 = Sta. 64+03.46 (MP 44.73) Sta. 86+00.00 (MP 45.14), -4.0000%, 0.34 miles Sta. 104+00.00 (MP 45.48), -0.4440%, 0.34 miles Sta. 122+00.00 (MP 45.82), -3.2000%, 0.19 miles Sta. 132+00.00 (MP 46.01), -5.8000%, 0.19 miles Sta. 142+00.00 (MP 46.20), -4.9000%
Annual Average Daily Traffic (AADT)	2518 (Year 2000)
Percent Trucks	5.25 (Year 2000)
Average Number of Accidents per Year	19.3 Total (0.0 Trucks)

Number of Accidents - Crash data for State Route 83 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 35.61 (south) to MP 46.20 (north)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 58 (19.3 per year) and the total truck crashes were 0 (0 per year).

Relationship of Percent Downgrade and Length of Downgrade - There are no segments along State Route 83 which exceed the curve presented in Figure 209.4A (*Roadway Design Guidelines*). One segment contains an average downgrade of –4.1035% over approximately 4.12 miles, but this is not enough to warrant a need according to the Roadway Design Guidelines.

4.2.11 Potential Project Location 11 – Interstate Route 8 EB (MP 20): Telegraph Pass

The Yuma District identified the area surrounding MP 20 on I-8 EB as a potential site for a truck escape ramp (TER). **Table 4.2.9** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.9
Interstate Route 8 EB Location

Interstate Route 8 EB Location, I-8 MP 20	
Variable	**Description**
Mainline Station Range	Sta. 643+00.00 (west) to Sta. 1363+00.00 (east) Several station equations between.
Milepost Range (Approximate)	MP 11.27 (west) to MP 24.40 (east)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 643+00.00 (MP 11.27), +0.5800%, 0.76 miles Sta. 647+20.72 = Sta. 647+19.97 (MP 11.35) Sta. 683+00.00 (MP 12.03), +0.4500%, 1.27 miles Sta. 747+62.57 = Sta. 747+62.66 (MP 13.25) Sta. 750+00.00 (MP 13.29), +1.1000%, 0.42 miles Sta. 771+94.89 (MP 13.71), +1.3849%, 0.24 miles Sta. 784+50.00 (MP 13.95), -0.5047%, 0.74 miles Sta. 816+42.06 = Sta. 816+64.60 (MP 14.55) Sta. 824+00.00 (MP 14.68), +1.2252%, 0.81 miles Sta. 856+71.18 = Sta. 396+00.00 (MP 15.30) Sta. 406+00.00 (MP 15.49), +2.0000%, 0.09 miles Sta. 411+00.00 (MP 15.58), +1.3440%, 0.30 miles Sta. 427+00.00 (MP 15.89), +1.4300%, 0.28 miles Sta. 442+00.00 (MP 16.17), +1.3570%, 0.13 miles Sta. 449+00.00 (MP 16.30), 1.4700%, 0.11 miles Sta. 455+00.00 (MP 16.42), +1.2800%, 0.15 miles Sta. 463+00.00 (MP 16.57), +0.8640%, 0.21 miles Sta. 474+00.00 (MP 16.78), +3.7800%, 0.17 miles Sta. 483+00.00 (MP 16.95), +1.5860%, 0.16 miles Sta. 489+42.69 = Sta. 489+41.36 (MP 17.07) Sta. 491+50.00 (MP 17.11), +5.0000%, 0.36 miles Sta. 510+50.00 (MP 17.47), -2.0370%, 0.26 miles Sta. 524+00.00 (MP 17.72), +2.2500%, 0.23 miles Sta. 536+00.00 (MP 17.95), +2.4300%, 0.13 miles Sta. 543+00.00 (MP 18.08), +2.9000%, 0.19 miles Sta. 553+00.00 (MP 18.27), +4.2400%, 0.57 miles Sta. 583+00.00 (MP 18.84), -6.0000%, 1.37 miles Sta. 598+09.45 = Sta. 598+03.84 (MP 19.13) Sta. 655+50.00 (MP 20.22), -3.2857%, 0.63 miles Sta. 689+00.00 (MP 20.85), +0.1285%, 0.33 miles Sta. 690+61.11 = 1177+18.70 (MP 20.88) Sta. 1193+00.00 (MP 21.18), +0.1243%, 0.70 miles

	Sta. 1230+00.00 (MP 21.88), -0.7778%, 0.51 miles Sta. 1257+00.00 (MP 22.39), +0.3462%, 0.49 miles Sta. 1283+00.00 (MP 22.88), +2.0000%, 0.32 miles Sta. 1300+00.00 (MP 23.21), -2.6669%, 0.20 miles Sta. 1310+75.00 (MP 23.41), +0.1136%, 0.59 miles Sta. 1342+00.00 (MP 24.00), +0.5771%, 0.40 miles Sta. 1363+00.00 (MP 24.40), +0.3889%
Annual Average Daily Traffic (AADT)	17980 (Year 2000, 9800 Year 1998)
Percent Trucks	5.35 (Year 2000, 14.23 Year 1998)
Average Number of Accidents per Year	24.7 Total (2.3 Trucks)

Number of Accidents - Crash data for Interstate Route 8 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 11.27 (west) to MP 24.40 (east)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 74 (24.7 per year) and the total truck crashes were 7 (2.3 per year). The first harmful event in the truck crashes included: 4 collisions with other motor vehicle, 1 collision with guardrail, and 2 all other non-collision.

Relationship of Percent Downgrade and Length of Downgrade - There are no segments along Interstate Route 8 which exceed the curve presented in Figure 209.4A (*Roadway Design Guidelines*). There are two segments that approach the curve, both of which are approximately located between MP 19 and MP 20.

The first segment has an average downgrade of –6.00% over 1.37 miles while the second has an average downgrade of –4.6429% over 2.01 miles.

4.2.12 Planned Project Location 1 – US Route 60 WB (MP 280)

The Globe District identified the area surrounding MP 280 on US Route 60 WB as a planned site for a truck escape ramp (TER). Data collected for the planned location on US 60 WB at MP 280 is presented above in **Section 4.2.1** (See **Table 4.2.1**).

Number of Accidents - Refer to **Section 4.2.1** above for information on the planned location on US 60 WB at MP 280.

Relationship of Percent Downgrade and Length of Downgrade - Refer to **Section 4.2.1** above for information on the planned location on US 60 WB at MP 280.

4.2.13 Planned Project Location 2 – State Route 68 WB (MP 5.75)

Completed in July 1999, the Final Design Concept Report (DCR) for State Route 68 recommended replacing the existing truck escape ramp (TER) located at MP 1.70 to MP 5.50. The project is currently under constructed as a design-build project. The new location is nearly 7 miles into the descending grade, and is located above the first intersection (La Puerta Road), which is likely to become signalized in the future. The new location is located approximately 6 miles from the summit of the 11 mile downgrade, compared with the existing location approximately 10 miles from the summit. The new TER will have an approximate length of 3, 100 feet with an approximate grade of –4.9%.

The DCR also notes that the existing safety pull-out, which is located just past the Union Pass crest (approximate MP 11.9) will be replaced in approximately the same location. **Table 4.2.10** shows the limits of descent, vertical geometry, ADT, percent trucks and accident summary.

Table 4.2.10
State Route 68 WB Location

State Route 68 WB Location, SR 68 MP 5.75	
Variable	**Description**
Mainline Station Range	Sta. 650+40.00 (east) to Sta. 87+00.00 (west)
Milepost Range (approximate)	MP 12.27 (east) to MP 1.60 (west)
Vertical Geometry (Including: station, milepost, grade and length.)	Sta. 650+40.00 (MP 12.27), -6.0000%, 1.71 miles Sta. 560+00.00 (MP 10.56), -4.7039%, 0.38 miles Sta. 540+00.00 (MP 10.18), -5.9524%, 0.40 miles Sta. 519+00.00 (MP 9.78), -5.5526%, 0.36 miles Sta. 500+00.00 (MP 9.42), -4.8306%, 0.64 miles Sta. 466+00.00 (MP 8.77), -5.0600%, 0.40 miles Sta. 445+00.00 (MP 8.38), -3.6326%, 0.33 miles Sta. 427+50.00 (MP 8.05), -5.1693%, 0.62 miles Sta. 395+00.00 (MP 7.43), -5.9732%, 0.76 miles Sta. 355+00.00 (MP 6.67), -4.9291%, 1.34 miles Sta. 284+50.00 (MP 5.34), -2.7778%, 0.17 miles Sta. 275+50.00 (MP 5.17), -4.4000%, 0.38 miles Sta. 255+50.00 (MP 4.79), -3.0000%, 0.21 miles Sta. 244+50.00 (MP 4.58), -6.0000%, 0.34 miles Sta. 226+50.00 (MP 4.24), -4.3947%, 0.36 miles Sta. 207+50.00 (MP 3.88), -5.0490%, 0.52 miles Sta. 180+00.00 (MP 3.02), -5.5361%, 0.34 miles Sta. 162+00.00 (MP 3.02), -5.0762%, 0.20 miles Sta. 151+50.00 (MP 2.82), -4.5826%, 0.22 miles Sta. 140+00.00 (MP 2.60), -4.8850%, 0.38 miles Sta. 120+00.00 (MP 2.22), -3.7075%, 0.15 miles Sta. 112+00.00 (MP 2.07), -5.0876%, 0.47 miles Sta. 87+00.00 (MP 1.60), -3.7713%
Annual Average Daily Traffic (AADT)	8201 (Year 2000)
Percent Trucks	5.90 (Year 2000)
Average Number of Accidents per Year	101.0 Total (7.3 Trucks)

***Number of Accidents* -** Crash data for State Route 68 was obtained from the Intermodal Transportation Division (ITD), Traffic Records Section. The area analyzed included the entire mountain downgrade on which the proposed TER would exist (MP 12.27 (east) to MP 1.60 (west)). The crash data obtained was over a period of three years, from November 1998 to November 2001. Total crashes were found for all vehicles and truck tractor/semi-trailer. The crash data for trucks were further investigated to find the types of crashes most prevalent.

The total crashes for the three-year period were 303 (101.0 per year) and the total truck crashes were 22 (7.3 per year). The first harmful event in the truck crashes included: 20 collisions with other motor vehicle, and 2 collisions with other fixed objects.

Relationship of Percent Downgrade and Length of Downgrade - There were three segments analyzed along westbound State Route 68 from MP 12.5 to MP 1.60, of which two segments exceeded the curve presented in Figure 209.4A (*Roadway Design Guidelines*).

The first segment analyzed took into account the entire length from MP 12.27 to MP 1.60. The segment had a total length of 10.67 miles and an average downgrade of –4.8318%. The second segment was from MP 12.27 to MP 5.34 (the upper half of the total downgrade). The segment had a total length of 6.93 miles and an average downgrade of –5.18 miles. Both these segments indicate that the need has been warranted.

The final segment analyzed was the lower half of the total downgrade from MP 5.34 to MP 1.60. This segment had a total length of 3.74 miles and an average downgrade of –4.54%. While this segment did not exceed the curve displayed in Figure 209.4A, the first segment, which incorporated the entire downgrade, did. Therefore, there are two locations that are warranted along State Route 68 in accordance with Figure 209.4A of the *Roadway Design Guidelines*.

4.3 Conclusions

Based on the recommendations from the various ADOT Districts throughout the State, a total of 10 locations were deemed “potentially needed” and two locations were already in the planning or design phase. All 12 locations were researched to determine vertical geometry, AADT, percent trucks and the average number of accidents the location accounts for. **Table 4.3.1** below summarizes the findings.

Based on the information presented, including the location recommendations made by the various ADOT Districts and the analysis of the vertical geometry along existing routes at the District specified locations, every location presented, with the exception of SR 83 (MP 42) and I-8 (MP 20) either meets or exceeds Figure 209.4A in the *Roadway Design Guidelines*.

Having collected the necessary information and determined which locations meet the determination of need as presented in the *Roadway Design Guidelines*, the next step in the process will be to conduct a field review of the above locations and present a summary of the findings.

Table 4.3.1
Summary of Potentially Needed TER Locations

	Findings of Potentially Needed TER Location Analysis					
	Location	**Percent Downgrade**	**Length of Downgrade**	**AADT**	**Percent Trucks**	**Average Annual Accidents**
Potentially Needed	US 60 (MP 280)	[1]-5.2641% (WB) [2]-5.0513% (EB)	[1]3.71 miles [2]3.48 miles	2,752	3.78%	22.7 (Total)
Potentially Needed	SR 87 (MP 215)	-5.0353% (SB)	3.82 miles	10,415	6.43%	119.3 (Total)
Potentially Needed	SR 87 (MP 230)	-5.8697% (NB)	3.72 miles	10,415	6.43%	119.3 (Total)
Potentially Needed	SR 260 (MP 232)	-4.2357% (WB)	5.15 miles	6,500	18.78%	25.0 (Total)
Potentially Needed	US 191 (MP 166)	No information available.		2,630	11.90%	17.7 (Total)
Potentially Needed	US 191 (MP 153)	-6.0170% (NB)	2.28 miles	2,630	11.90%	43.3 (Total)
Potentially Needed	US 191	**District has indicated this location is the same as the previous.**				
Potentially Needed	SR 78 (MP 153)	No information available.		392	11.90%	4.3 (Total)
Potentially Needed	SR 80	**District has indicated this location is no longer being considered.**				
Potentially Needed	SR 83 (MP 42)	-4.1035% (NB)	4.12 miles	2,518	5.25%	19.3 (Total)
Potentially Needed	I-8 (MP 20)	[1]-6.0000% (EB) [2]-4.6429% (EB)	[1]1.37 miles [2]2.01 miles	17,980	5.35%	24.7 (Total)
Planned	US 60 (MP 280)	[1]-5.2641% (WB) [2]-5.0513% (EB)	[1]3.71 miles [2]3.48 miles	2,752	3.78%	22.7 (Total)
Planned	SR 68 (MP 5.75)	[1]-4.8318% (WB) [2]-5.18% (WB)	[1]10.67 miles [2]6.93 miles	8,201	5.90%	101.0 (Total)

Chapter 5
Potential Truck Escape Ramp (TER) Locations

5.1 Introduction

Chapter 5 represents the fourth working paper prepared as part of the Truck Escape Ramp Study being prepared for ADOT. The first three working papers (Chapters 2, 3 and 4) dealt with the following subjects:

- In Chapter 2, *Evaluation of Conditions at Existing Truck Escape Ramp (TER) Sites*, the characteristics of each TER that was operational in April 2002 were studied and documented. These characteristics included information such as horizontal and vertical geometry including degree of curvature and grade, crash rates, average daily traffic (ADT) and TER descriptions. The information provided a comprehensive summary of existing ADOT TERs.

- Chapter 3, *Documenting the State of the Practice*, provided a review of ADOT criteria for TERs as well as criteria employed by other states in mountainous regions of the United States. Documentation published by various federal agencies was also reviewed and included in Chapter 3. The information illustrated what the current theory and practice was with respect to the installation of TERs and how these theories and practices related to what was being done within Arizona.

- Chapter 4, *Evaluation of Conditions at Potential Truck Escape Ramp (TER) Locations*, focused on potential TER sites recommended by the District Engineers. Information was presented in a similar format as Chapter 2, with the information generated in Chapter 3 providing support for the recommended sites.

Following the review of the initial three working papers with ADOT personnel, the scope for Chapter 5 was developed. The project and review team decided the approach to locating potential TER sites should be based in large part of the number of crashes that occur within a stretch of highway as well as the grade along that stretch. To this end, the purpose of this chapter is to identify locations that meet ADOT's *Roadway Design Guidelines* and *Truck Escape Ramp Policy*. To do this, information obtained from ADOT was used to narrow down possible locations to those that have the potential to reduce the greatest number and severity of crashes. All segments of the state highway system were included in the review and analysis presented below.

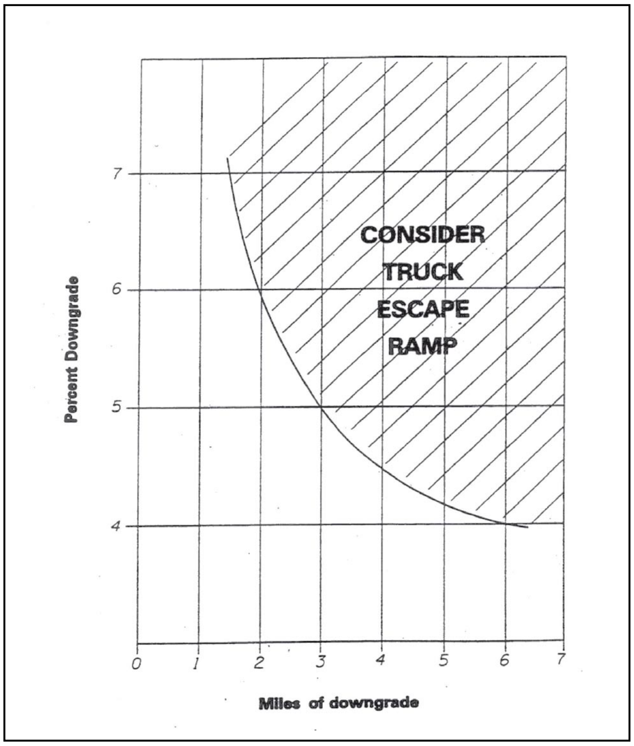
5.2 ADOT Criteria

The ADOT *Roadway Design Guidelines* state that the determination of need for truck escape ramps relies on three criteria:

1. The number of crashes that occur in conjunction with a long sustained downgrade.
2. Areas where the combination of percent downgrade and length of downgrade exceed the curve presented in Figure 209.4A (See **Figure 5.2.1**) of the *Roadway Design Guidelines*.

3. Information obtained from professional truck drivers, wrecker operators, and Department of Public Safety officers and by inspection of crash data.

Figure 5.2.1
Determination of Need (ADOT Figure 209.4A)



Once the determination of need has been established, the next step is the determination of location. The *Roadway Design Guidelines* includes the following considerations for the location of TERs:

1. The location of a TER is influenced by the relationship of attainable runaway speeds and the highway design speed.
2. TER location is also influenced by terrain and construction cost considerations (right-of-way and embankment costs).
3. TERs should only be considered on the lower half of a downgrade.
4. TERs should not be located on curves.

5.3 Crash Data Review

From a review of five years of data from the ADOT Accident Records System (July 1, 1997 through June 30, 2002), segments of highway that had five or more crashes and/or a fatal crash that involved truck trailers were identified. The 33 segments that met this criterion are listed in **Table 5.3.1** and shown in **Figure 5.3.1**. The 33 segments ranged in distance from 13 to 58 miles.

ADOT is considering funding TERs through HES funds for which projects are evaluated based upon a Benefit Cost Ratio (B/C). In the B/C analysis, fatal crashes are valued at $2,600,000, injury crashes are valued at $78,000, and property damage only crashes are valued at $2,000 in calculating benefits. With fatal crash elimination considered over 33 times as valuable as injury crashes in the benefit calculation, it was determined that those segments that did not include fatalities would not be considered in this analysis. This left 26 roadway segments for additional evaluation.

Figure 5.3.1
Segments to be Studied Further

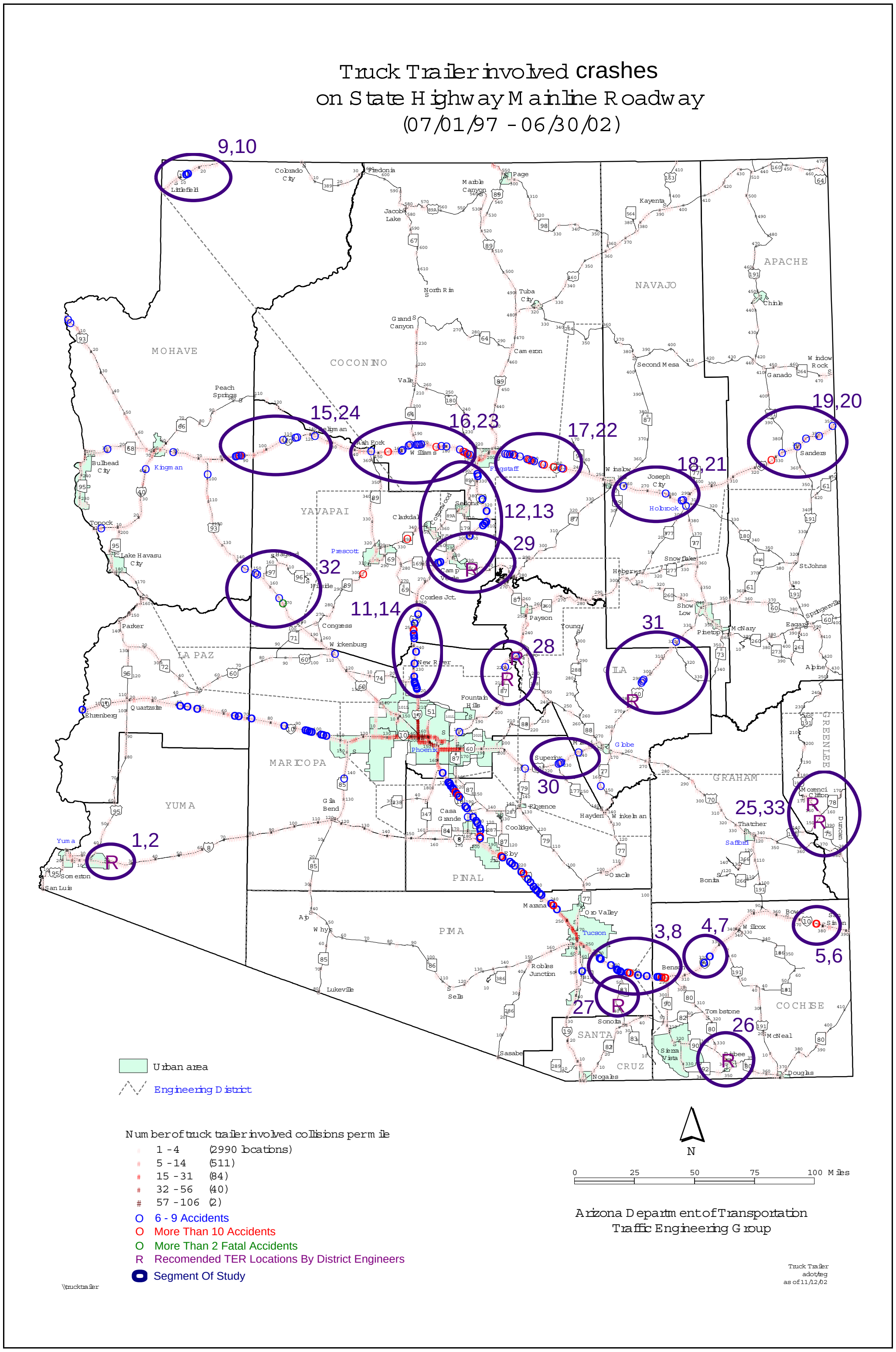


Table 5.3.1
Segments to be Studied Further

ADOT Truck Escape Ramp (TER) Study							
Crash Data Review							
Segment	Route	From Milepost	To Milepost	Distance (mi.)	Crashes Involving Injury	Fatalities	Fatality MP
1	I-8 (EB)	11	30	19	5	0	NA
2	I-8 (WB)	27	11	16	6	0	NA
3	I-10 (EB)	270	301	31	29	3	284, 300, 301
4	I-10 (EB)	316	330	14	8	2	319 (2)
5	I-10 (EB)	370	384	14	13	1	370
6	I-10 (WB)	385	371	14	1	1	385
7	I-10 (WB)	328	315	13	7	1	315
8	I-10 (WB)	300	270	30	29	1	295
9	I-15 (NB)	0	28	28	20	0	NA
10	I-15 (SB)	28	0	28	9	1	0
11	I-17 (NB)	220	259	39	42	7	222 (2), 225, 231 (2), 232, 255
12	I-17 (NB)	280	338	58	34	5	289, 293, 308, 317, 337
13	I-17 (SB)	338	280	58	28	3	301, 302, 316
14	I-17 (SB)	259	220	39	26	0	NA
15	I-40 (EB)	80	125	45	30	1	89
16	I-40 (EB)	140	195	55	53	2	150, 151
17	I-40 (EB)	205	240	35	54	2	207, 218
18	I-40 (EB)	255	294	39	42	4	260, 279, 282, 290
19	I-40 (EB)	320	359	39	40	9	320, 322, 324, 328, 340 (2), 341, 342, 356
20	I-40 (WB)	359	320	39	24	3	345, 356 (2)
21	I-40 (WB)	295	255	40	22	2	276, 284
22	I-40 (WB)	240	205	35	34	2	207, 237
23	I-40 (WB)	195	140	55	48	3	142, 150, 155
24	I-40 (WB)	125	80	45	34	3	90, 100, 101
25	SR 78	163	171	8	0	0	NA
26	SR 80	331	350	19	9	1	331
27	SR 83	44	53	9	1	0	NA
28	SR 87	205	231	26	11	3	220, 221, 228
29	SR 260	215	245	30	11	2	216 (2)
30	US 60	220	240	20	20	1	240
31	US 60	281	319	38	25	7	284, 291 (2), 293, 297 (2), 315
32	US 93	142	179	37	29	7	146, 149, 169 (3), 170, 175
33	US 191	149	175	26	4	0	NA

5.4 Location Determination

Roadway grade is a critical factor in determining the need for a TER. Grade data is coded into the ADOT Highway Performance Monitoring System (HPMS) database, but ADOT advised us that because of numerous changes in the section limits that have been made over the years since the grade data was input into the system, they have little confidence in the accuracy of the data. Therefore, it was determined that the most efficient method to review grade data was through the use of the ADOT video log system.

The next step in the process was then to view the video logs of the 26 roadway segments in which a fatal truck trailer crash had occurred. Of the 26 segments, 13 locations were identified that met grade considerations for a truck escape ramp. Two of the 13 already included truck escape ramps and one, through the Virgin River Gorge, was eliminated because of the difficulty in constructing a TER in this environmentally sensitive area. The remaining 10 locations are listed in **Table 5.4.1** and shown in **Figure 5.4.1**. As can be seen in **Figure 5.4.1**, four of the identified locations were recommended by the district engineers. These locations include one in Segment 26, two in Segment 28, and one in Segment 29.

Since exact grades were impossible to obtain from video logs alone, the grade percentages given in **Table 5.4.1** were estimated from their relation to confirmed signed grades that were seen on the film. Each of the 10 locations is described below.

I-17 SB, MP 297.42 – MP 287.52, Northwest of Camp Verde
This area is located in Segment 13, which is an area of I-17 that runs southbound a distance of 58 miles from MP 338 through MP 280. The number of crashes involving injury in this segment is 28, along with 3 fatalities.

From MP 297.42 through MP 293.17 there was an approximate grade of -4% to -5% that runs for 4.25 miles. This is followed by a relative flat section of 0.86 miles, then a -5% to -6% grade for another 0.69 miles and a section of road that rises slightly for 1.02 miles. From MP 290.60 through MP 287.52 (3.08 miles) the grade is about -5% to -6% as well before running flat for some time.

The first grade runs for just enough miles at just enough grade to fit within ADOT's curve. This accompanied by the short flat section and resumption of the downgrade for another 0.69 miles makes this a location for further study. The very slight upgrade for approximately 1.02 miles may be enough to slow the vehicle. Although with the additional 3.08-mile downgrade after this, a closer look should be taken at the extent of the upgrade to determine for sure.

Figure 5.4.1
Areas To Be Evaluated Further

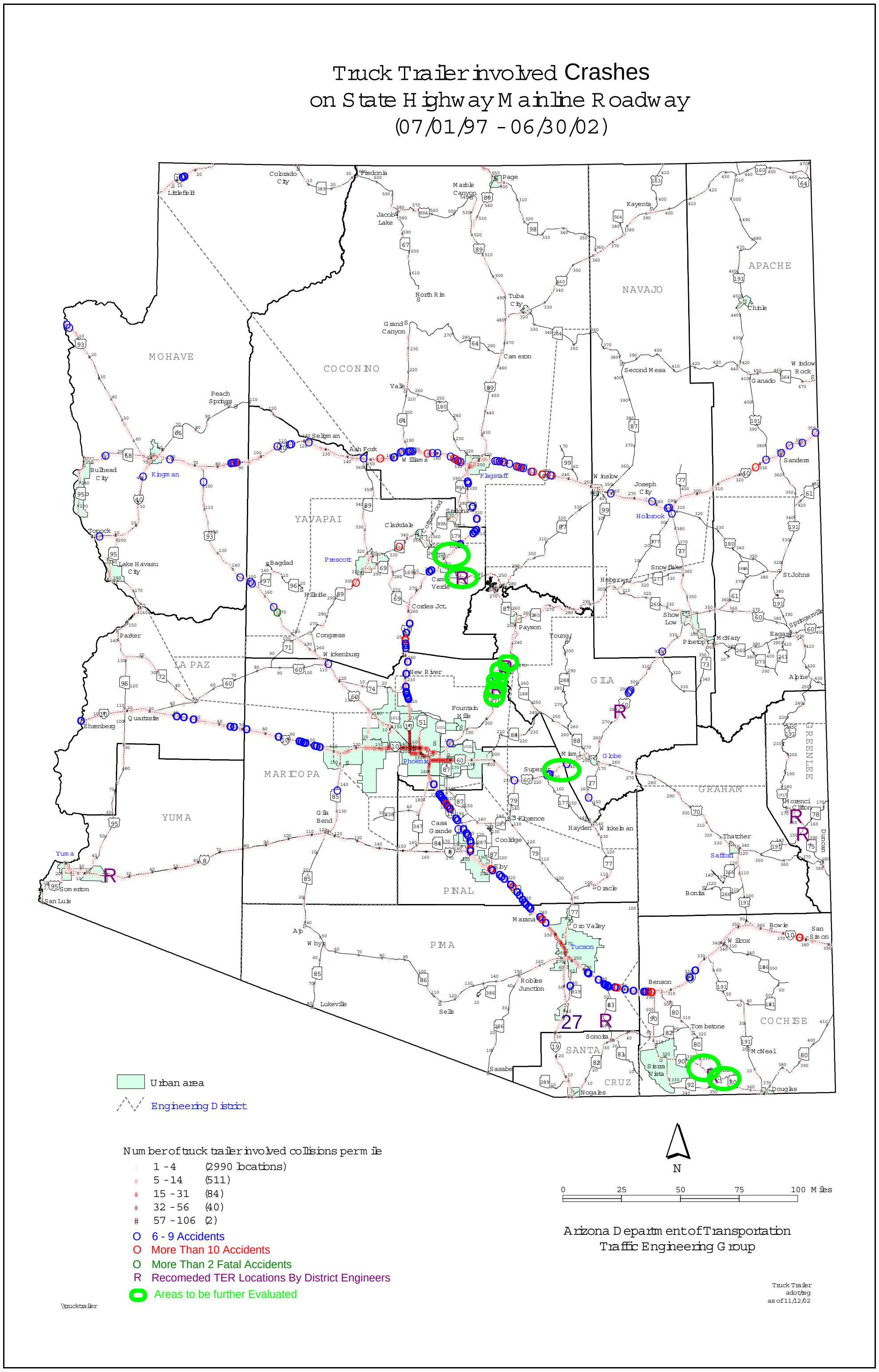


Table 5.4.1
Locations for Further Evaluation

ADOT Truck Escape Ramp (TER) Study							
Recommended Locations for Further Evaluation							
Segment	**Roadway**	**Direction**	**Grade**	**Start MP**	**End MP**	**Length**	**Comments**
13	I - 17	SB	-4% to -5%	297.42	293.17	4.25	
			Flat	293.17	292.31	0.86	
			-5% to -6%	292.31	291.62	0.69	
			Slightly Up	291.62	290.60	1.02	
			-5% to -6%	290.60	287.52	3.08	
			Flat				
26	SR 80	WB	-6% to -7%	338.85	334.00	4.85	
			-3% to -4%	334.00	331.50	2.50	Long series of small grades and short flat areas
			Flat				
26	SR 80	EB	Signed -6% to -7%	338.83	341.37	2.54	Area of Bisbee, i.e. driveways, stores, etc.
			-6% to -7%	341.37	344.20	2.83	
			Flat				
28	SR 87	NB	-5% to -6%	205.36	207.87	2.51	
			Flat	207.87	208.91	1.04	
			-5% to -6%	208.91	212.73	3.82	
			Flat				
28	SR 87	NB	Safety Pullout	226.04			
			-5% to -6%	226.22	228.72	2.50	
			Flat				
28	SR 87	SB	-6% to -7%	231.75	228.73	3.02	
			Flat				
28	SR 87	SB	Safety Pullout	225.07			
			Signed -6% Grade	224.92	224.04	0.89	
			Signed -5% Grade	224.04	221.48	2.55	
			Flat				
28	SR 87	SB	-4% to -5%	216.74	212.67	4.07	
			Flat				
29	SR 260	WB	Signed -6% Grade	237.94	228.98	8.96	
			Flat				
30	US 60	EB	Signed -6% Grade - 11 miles	231.70	236.47	4.77	Rural Driveways at MP 234.61 Ending @ 236.49
			Signed -6% Grade - 7 miles	236.47	239.54	3.07	
			Signed -6% Grade - 4 miles	239.54	240.00	0.46	
			Continues down at end of site: 240.00				

SR 80 WB, MP 338.85 – MP 331.50, Northwest of Bisbee

This area is located in Segment 26, which is an area of SR 80 that runs in both cardinal directions a distance of 19 miles from MP 331 through MP 350. The number of crashes involving injury in this segment is 9 along with 1 fatality.

Two locations were found in this segment that met the main ADOT criteria for a truck escape ramp. The first is an area that runs westbound starting at MP 338.85. From this milepost to MP 334.00 there was an approximate grade of -6% to -7% that runs for 4.85 miles. This is followed by a long series of -3% to -4% grades and short flat sections from MP 334 through MP 331.50 for 2.5 miles.

This first location has a grade and distance that puts it well within the ADOT guidelines for a TER. This followed by the 2.5-mile section of small grades and flat sections solidifies this as a location to further study. It should also be noted that this coincides with the Safford District Engineer's recommendation that a TER be placed on SR 80 in the area leaving Bisbee.

SR 80 EB, MP 338.83 – MP 344.20, Northeast of Bisbee

The second area of segment 26 runs eastbound starting at MP 338.83. From this milepost through MP 344.20 there is about a -6% to -7% grade. It should be noted though that from MP 338.83 through 341.37 is a populated area. If not populated it would be an ideal location for a TER but because of the circumstance this area will need additional study.

SR 87 NB, MP 205.36 – MP 212.73, Between Fountain Hills & Payson

This location is in Segment 28, which is an area of SR 87 that runs in both cardinal directions a distance of 26 miles from MP 205 through MP 231. The number of crashes involving injury in this segment is 11, along with 3 fatalities.

Five locations were found in this segment that met the main ADOT criteria for a truck escape ramp. The first is an area that runs northbound starting at MP 205.36. From this milepost to MP 207.87 there was an approximate grade of -5% to -6% that runs for 2.51 miles. A relatively flat section for 1.04 miles follows this. From MP 208.91 through MP 212.73 (3.82 miles), the roadway resumes its -5% to -6% decline before running flat again.

The 3.82-mile portion of this area is long enough and steep enough to meet the main ADOT criteria for a TER.

SR 87 NB, MP 226.22 – MP 228.72, Between Fountain Hills & Payson

The second area of segment 28 runs northbound and begins at MP 226.22. This portion has a -5% to -6% downgrade and runs 2.50 miles through MP 228.72. This area is just on the border of the ADOT criteria for a possible TER location. This knowledge coupled with the fact that there is a safety pullout would suggest that this area may not need a TER. It should be noted that this compares closely with the Prescott District Engineer's recommendation that a TER be placed on SR 87 at MP 230.

SR 87 SB, MP 231.75 – MP 228.73, Between Fountain Hills & Payson
The third location in segment 28 runs southbound and begins at MP 231.75. This location has a -6% to -7% downgrade for 3.02 miles through MP 228.73. This combination of length and grade meets well within the ADOT criteria and should be studied further for a possible TER.

SR 87 SB, MP 224.92 – 221.48, Between Fountain Hills & Payson
The fourth location in segment 28 also runs southbound and begins at MP 224.92. There is a signed grade of -6% that runs 0.89 miles through MP 224.04. From here the grade lessens to a signed grade of -5% through MP 221.48 (2.55 miles). This combination of length and grade also meets the ADOT criteria and should be studied further for a possible TER.

SR 87 SB, MP 216.74 – MP 212.67, Between Fountain Hills & Payson
The fifth and final location in segment 28 also runs southbound and begins at MP 216.74. This portion has a -4% to -5% downgrade and runs 4.07 miles to MP 212.67. While this grade is not especially steep, it runs long enough to fall within the ADOT criteria and should be studied further. It should also be noted that this coincides with the Phoenix District Engineer's recommendation that a TER be placed on SR 87 at MP 215.

SR 260 WB, MP 237.94 – MP 228.98, Southeast of Camp Verde
This location is in Segment 29, which is an area of SR 260 that runs in both cardinal directions a distance of 30 miles from MP 215 through MP 245. The number of crashes involving injury in this segment is 11, along with 2 fatalities.

The area runs westbound starting at MP 237.94. At MP 228.98 there is a signed -6% grade for 8.96 miles that ends at MP 228.98.

This location has a downgrade and a very long distance that puts it well within the ADOT curve (**Figure 5.2.1**) and meets all guidelines for a TER. Therefore it is recommended that this area be studied further. It should also be noted that this coincides with the Prescott District Engineer's recommendation of placing a TER on SR 260 at MP 232.

US 60 EB, MP 231.70 – 240.00+, West of Globe
This location is in Segment 30 which is an area of US 60 that runs eastbound a distance of 20 miles from MP 220 through MP 240. The number of crashes involving injury in this segment is 20, along with 1 fatality.

The location begins at MP 231.70 and runs through MP 240.00. At this point it is still in decline. The entire 8.30-mile length is signed with multiple -6% grade signs. The first of which is listed at 11 miles, so it can be assumed the downgrade continues for an additional 3 to 4 miles beyond MP 240.

As with the previous location, this location has a downgrade for a very long distance that puts it well within the ADOT curve and meets all guidelines for a TER. It should be noted that from MP 234.61 through MP 236.49 there are a smattering of rural driveways. This should not be a factor though since they are in the beginning of the area and ADOT suggests putting truck escape ramps near the last half of the grade. Therefore it is recommended that this area be studied further.

Chapter 6
Summary and Recommendations

6.1 Existing Truck Escape Ramp Sites

As presented in Chapter 2, since their initial appearance in Arizona in 1982, truck escape ramps (TERs) have been completed throughout the State. Every TER constructed by ADOT thus far has been of the arrester bed design, with a majority being on descending grade (non-gravity). In addition, every existing TER is equipped with wrecker anchors and a service road for removal and maintenance purposes, along with a "last chance" device in the form of an aggregate mound.

A review of the existing TERs in Arizona found that almost all were constructed on the lower half of the downgrade on roadways with grades ranging from –4.6% to –6.0%. All have proven to be effective in stopping out-of-control vehicles and are useful countermeasures for reducing the severity of runaway truck accidents.

A review of as-built plans did indicate inconsistencies in the design of arrester beds in Arizona, primarily in the widths and depths of the arrester bed itself. One item that has held true for every TER in Arizona is that they have probably reduced the loss of life and property damage along Arizona highways, as is evident by their usage.

6.2 State of the Practice

As presented in Chapter 3, the current practices in Arizona are in line with those of other states that require the use of TERs to assist out-of-control vehicles. While the criteria used to determine need and location, as well as design standards, varies across the country, the practices used in Arizona do not appear to be at either end of the spectrum, but rather occupy the middle.

In Arizona, the determination of need and location are applied liberally based on current design policy, resulting in many areas where both need and location are sufficient to support additional study of these sites for potential TERs. No changes to the current policy on the determination of need and location are being proposed as a result of this study

6.3 Potential Truck Escape Ramp Locations

As presented in Chapters 4 and 5, two methods were undertaken to determine potential locations throughout the state for additional TERs. In Chapter 4, a review of 12 sites submitted by District Engineers was undertaken to determine if they met the criteria currently presented in the *Roadway Design Guidelines*.

In Chapter 5, a broader approach was taken by reviewing crash data and grades along all state highways within Arizona to determine segments that met the need and location criteria based on crash data and percent grades.

While neither Chapter 4 nor Chapter 5 recommends the construction of a TER at any particular site, they do present data that will assist ADOT decision-makers in choosing which locations should be studied in greater detail and which locations should no longer be considered as viable options. Sites where the need and location have been justified based on crash data, roadway geometry, site characteristics and benefit/cost analysis, should be eligible for Hazard Elimination and Safety (HES) Program funding for State highways. The process for determining eligibility for HES funds is outlined in the ADOT *Highway Safety Improvement Program (HSIP) Manual*.